Animals found living together in Shallow Inlets from the Sea, Long Island Sound

A TEXT-BOOK

IN

GENERAL ZOÖLOGY

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PREFACE

In offering to the educational public this text-book in general zoölogy, with its accompanying suggestions for laboratory work, we desire to explain in brief the method of construction we have followed.

The treatment of the phyla is in a descending order from the Arthropoda to the Protozoa, and in an ascending order from the fishes to man. After many years of experience with classes of young students we believe that an order of treatment resembling this is likely to yield the best results, although we do not deny that good results may be obtained with young students by following what is sometimes called the "order of evolution," beginning with the Protozoa. Although the chapters are interdependent, we think that there is sufficient unity in each to make it possible for the teacher to diverge from the order we have employed.

Whatever the order followed, it is evident that recitation on the chapters in the text-book should be held only after the pupil has made his study in the laboratory, for the text-book in science has its greatest usefulness in connecting, extending, and illuminating the work of the laboratory. Laboratory work brings the pupil in touch with actual things, and if the studies are properly conducted, they will aid in developing in the mind the power of independent judgment. But the young and untrained student cannot build up a conception of the science of zoölogy from the more or less isolated data of the laboratory; in this fact lies the justification of a text-book in zoölogy.

The function of the suggestions for laboratory work is to help the pupil to make the best use of his time, and to direct him in such a way that he will become more and more independent, and be able to study intelligently without detailed directions. It seems to us that the kind of directions given to pupils will depend not only on the teacher's training in zoölogy and his pedagogical skill, but also on the age and previous training of the pupils. The problem is a special one for each teacher to solve for himself. The directions given in the accompanying pamphlet, therefore, are to be regarded merely as suggestive.

The inductive method of presentation, in a necessarily modified form, has been followed in the earlier chapters of the text-book, as being the natural mode of approach to a new subject based upon laboratory work. After the study of the red-legged locust, for example, another animal that has easily recognizable relationship to this form is considered. Not until all the selected representatives of the Orthoptera have been described, are the characters of the order mentioned. By that time the pupil's mind is ready for the definition of Orthoptera. The conceptions of the larger groups of invertebrate classes and phyla are developed in the same manner.

It has been our earnest endeavor to present all the important aspects of zoölogy in a well-balanced account. The basis of the subject-matter in a text-book on zoölogy is necessarily morphological. The pupil must have some understanding of the appearance of animals and their organs before he can be supposed to think clearly regarding the uses of the organs or the relation of the animals to their environment. We have described the appearance of nearly all the animals mentioned. In certain selected cases we have described the structure and the functions of the systems of internal organs, and the development of the individual; and in appropriate connections we have spoken of the economic importance of animals, and have given brief sketches of the geographical distribution and the geological history of races. The rapidly developing science of comparative psychology is now sufficiently precise to justify the inclusion in a work of this kind of some of the important studies of the mental behavior of animals. We hope that the facts selected will give a general notion of the increasing complexity of the mental life in the higher animals. We have also presented in as simple a way as possible the doctrine of evolution. Finally, the last chapter deals with the historical development of the science of zoölogy. It should aid in giving the pupil the necessary perspective for appreciating the processes by which this organized body of knowledge came into existence.

The principles of physiology are reserved for full explanation in the study of the earthworm in Chapter XVI. We desire here to express our deep obligation for the inspiration and example of a similar study presented in *General Biology* by Professors W. T. Sedgwick and E. B. Wilson. We are indebted to them and their publishers for several figures illustrating the development of the earthworm. Our purpose in delaying the scientific treatment of the principles of physiology, instead of discussing them in the first chapters, is a double one. In the first place, too much abstraction at the beginning of an exposition is likely to prove discouraging to even a willing student; in the second place, the conception of physiological processes, it seems reasonable to believe, can be formed best after the learner has some knowledge of systems of organs, including, of course, an elementary knowledge of their uses. It then matters little whether the student learns the more detailed facts of physiology from the earthworm or from some other animal, and it even matters little whether or not he actually sees all the organs in the animal where the processes are described as taking place.

We believe that the attention given in this book to the subject of animal ecology will prove to be justified. Although the ecological sections are set off from the other topics, it should not be forgotten that ecology, or the relation of organisms to their environment, has significance only when the subject is considered from the standpoint of the adjustment or the adaptation in the form of the parts of organisms to the life they carry on.

We have been to considerable pains to produce original figures that should be comprehensive as well as accurate, and, where the subject permitted, artistic. In this we have been assisted by three gentlemen whose ability is evident in their work: Mr. S. F.

Denton, of Wellesley, Mass., Mr. L. H. Joutel, of New York City; and Mr. E. N. Fischer, of Jamaica Plain, Mass. Mr. Denton made the drawings of the vertebrate dissections and the external view of the lizard and Oniscus. Mr. Joutel made the drawings of the insects and all the invertebrate dissections. Mr. Fischer executed the drawings of all the marine invertebrates shown in their natural environment, and also the ecological studies of the pond-snail, the garden-slug, the garden-spider, the leech, the fresh-water mussel, and the fresh-water sponge, besides copying many figures from publications. Mr. Wm. T. Oliver, of Lynn, Mass., made the numerals and the leader-lines for all the drawings.

We desire to acknowledge the kindness of Professor H. C. Bumpus, Director of the American Museum of Natural History, and of Professor H. F. Osborn, Curator of Vertebrate Paleontology, American Museum, in permitting us to make selections from numerous photographs. Mr. C. William Beebe, of the New York Zoölogical Park, supplied us with photographs of many vertebrates and some marine invertebrates. Several photographs in different chapters are from the authors' own collections. To the following publishers we acknowledge the privilege of using figures: American Book Company; D. Appleton & Co.; G. W. Crane & Co.; Doubleday, Page & Co.; Henry Holt & Co.; McClure, Phillips & Co.

It is our hope that the quotations which introduce the chapters will serve to suggest to the imagination of young students the poetic side of animal life and of nature generally. For some of the best quotations we are indebted to the search made by personal friends.

We are especially grateful to several zoölogists who have read various portions of the manuscript critically: Professors G. H. Parker and W. E. Castle, of Harvard University; Professor J. H. Comstock, of Cornell University; Professor H. S. Jennings, of the University of Pennsylvania; Professor M. A. Bigelow, of Teachers College, Columbia University; Dr. J. A. Allen, Mr. Frank M.

Chapman, and Professor R. W. Tower, of the American Museum of Natural History; and Dr. F. B. Sumner, of the College of the City of New York. For suggestions in regard to some of the more important drawings we extend our thanks to Professors E. L. Mark, G. H. Parker, W. E. Castle, Dr. H. W. Rand, and Dr. W. McM. Woodworth, of Harvard University; to Professor J. S. Kingsley, of Tufts College; and to Professor C. W. Hargitt, of Syracuse University.

Certain little-known species have been identified for us in the tunicates, leeches, holothurians, crustaceans, gasteropods, and sponges, respectively, by the following: Professor W. E. Ritter, of the University of California; Professor J. Percy Moore, of the University of Pennsylvania; Professor H. L. Clark, of Olivet College; Dr. Walter Faxon, of the Museum of Comparative Zoölogy, Cambridge, Mass.; Dr. L. P. Gratacap, of the American Museum of Natural History; Professor H. V. Wilson, of the University of North Carolina; and Mr. Edward Potts, of Philadelphia.

To Mr. D. C. MacLaren, of the DeWitt Clinton High School, we are very much indebted for transposing into equivalent English letters the roots of the Greek derivatives.

The Authors

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GENERAL ZOÖLOGY

CHAPTER I

THE COMMON RED-LEGGED LOCUST

Though I watch their rustling flight,
I can never guess aright
Where their lodging-places are;
'Mid some daisy's golden star,
Or beneath a roofing leaf,
Or in fringes of a sheaf,
Tenanted as soon as bound. — Edith M. Thomas.

Habitat and Distribution. Locusts are found almost everywhere in the United States, usually in fields, meadows, and along roadsides. They are often spoken of as grasshoppers, but, as we shall see later, they differ from the true grasshoppers in several important particulars. The species (see p. 95) which heads this chapter is one of the most widely distributed of the insects to which the name *locust* is correctly applied. It is known to naturalists as *Melan'oplus*[1] *fe'mur-ru'brum*. Its habitat (the locality where it is naturally found) comprises grassy areas in almost every state except on the high western plains, where its place is taken by a species much resembling it, — the Rocky Mountain locust (*Melanoplus spre'tus*). Another species, the lesser locust (*Melanoplus atlan'is*), somewhat smaller and darker in color, is also found in nearly every part of the country. These, and several other locusts, are about three centimeters (a little

[1] The first time a scientific name is used, a mark is placed after the accented syllable as an aid in pronunciation.

over an inch) in length, and resemble each other so closely that the following description will apply nearly as well to one as to another.

External Plan of Structure. The body is made up of a series of rings, called *somites* (Fig. 2), externally hardened by a horny substance, *chitin*, for protection of the interior organs. The somites are grouped in three clearly marked regions,— the *head*, *thorax*, and *abdomen* (Fig. 2, 1, 2–4, 5). While the characteristic appearance of a ring is clearer in the abdomen than elsewhere, it is nevertheless true that the head and thorax are made up of several somites, much altered and pressed together. The head probably consists of at least five somites, of which four bear appendages, the feelers, or *antennæ* (Fig. 2, 6); the jaws, or *mandibles* (Fig. 1, 2; Fig. 2, 8); the *first maxillæ* (Fig. 1, 4); and the *second maxillæ* (Fig. 1, 5). The thorax plainly consists of three somites, on each of which is borne a pair of *legs* (Fig. 2, 14, 15, 16). Ten somites can without much difficulty be distinguished in the abdomen (Fig. 2, 5). The external plan upon which the locust is built is thus seen to be a series of somites, of which the anterior (front) somites bear jointed appendages modified for various uses.

The Head. The short, several-jointed antennæ are organs of touch and of smell, and, in most insects, of hearing as well. The maxillæ are constructed on the plan of jaws, though fitted for guiding and holding food rather than for crushing it. Each maxilla bears a short, several-jointed "feeler," or *palpus* (Fig. 1, 4, 5; Fig. 2, 9, 11). The anterior boundary of the mouth is a flap-like piece, the upper lip, or *labrum* (Fig. 1, 1; Fig. 2, 7); and the posterior (hind) boundary is made by the union of the bases of the second maxillæ (Fig. 1, 5), forming a flap called the lower lip, or *labium* (Fig. 2, 10).

On the sides of the head are large, oval, *compound eyes* (Fig. 2, 12), composed externally of a number of transparent divisions, *facets*, each of which has beneath it the necessary structures for sight, so that the whole may be regarded as a mosaic of single eyes. In addition, there are simple eyes, or *ocelli* (Fig. 2, 13), placed in the form of a triangle on the front of the head. Notwithstanding these two kinds of eyes, it is doubtful whether the locust is able to perceive well the outlines of objects, or to distinguish much except light and movement. The ocelli probably do not perceive objects at a greater distance than a few inches, nor the compound eyes at a greater distance than a few feet. It has been surmised from the structure of the compound eyes that each facet perceives only a small part of the field of vision.

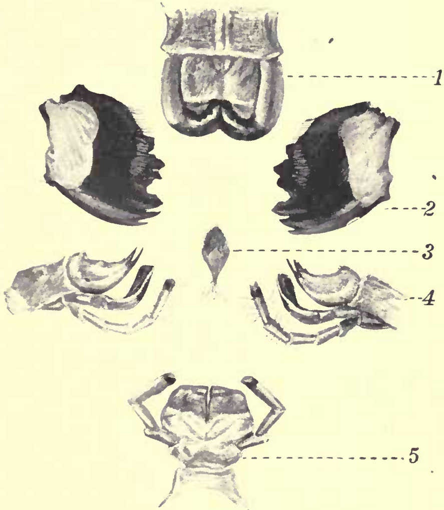


FIG. 1. Mouth-Parts of Red-Legged Locust. × 4

1, labrum; 2, mandible; 3, hypopharynx; 4, first maxilla with its palpus; 5, second maxillæ with palpi

The Thorax. The first somite of the thorax, called the *prothorax* (Fig. 2, 2), bears the first pair of legs. It is free from the rest of the thorax. The dorsal surface (Latin, *dorsum*, back) is thickened and raised into a ridge; the sides (lateral surfaces) are also thickened, and the whole forms a protective shield or collar. The second somite, the *mesothorax* (Fig. 2, 3), bears the second pair of legs; to the third, or *metathorax* (Fig. 2, 4), the last pair of legs is attached. Each leg is composed of a number of divisions, or segments, of which the principal are the thick *femur* (Fig. 2, 14, 15, 16; Fig. 3, 5) and the spiny *tibia* (Fig. 3, 6). Each leg ends in a series of three segments, forming the *tarsus* (Fig. 3, 7), the last segment of which bears two *claws* (Fig. 3, 8), with a pad, the *pulvillus* (Fig. 3, 9), between them.

Of the two pairs of *wings* (Fig. 2, 17, 18), the first is attached to the surface of the mesothorax, the second to the metathorax. The anterior pair is somewhat hardened, forming protective covers for the more delicate posterior wings, which are folded like a fan beneath them. The latter only are used in flight. The wings are simple extensions of the body-wall, and not jointed appendages like the legs. On the sides, just beneath the posterior edge of the collar on the prothorax, is a pair of breathing openings, or *spiracles* (not shown in the figure). Two spiracles are placed just above the junction of the second pair of legs (Fig. 2, 20), and the abdomen bears eight pairs along the sides (Fig. 2, 21, 22).

The Abdomen. The first abdominal somite is much larger than the others, though it does not form a complete ring, owing to the space occupied by the cavities for the insertion of the hind legs. Each side of this somite bears an oval spot consisting of a thin skin stretched across a small cavity and connected with a nerve, the whole forming an ear, or *auditory apparatus* (Fig. 2, 19). The end of the abdomen in the female is more tapering than in the male, and is furnished with two pairs of blunt spines, which form an egg-laying instrument, or *ovipositor* (Fig. 3, 36, 37).

The Digestive System. After this brief review of the main features of the external anatomy of the locust, we turn our attention to the organs of the interior. And first, owing to its size and the ease with which its parts may be examined, we may consider the digestive system. The function of the digestive system of an animal is to prepare the food for use by the different organs of the body. In the locust the organs of digestion are the food-tube, or *alimentary canal*, and its

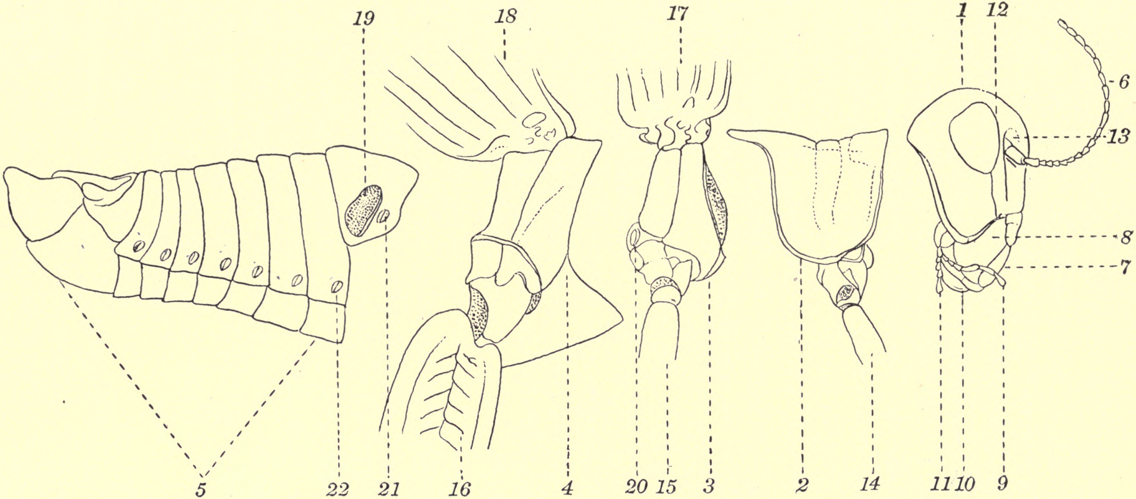


Fig. 2. External Anatomy of Male Locust. × 4. (After Kingsley)

1, head; 2, prothorax; 3, mesothorax; 4, metathorax; 5, abdomen; 6, antenna; 7, labrum; 8, mandible; 9, palpus of first maxilla (maxillary palpus); 10, labium; 11, palpus of second maxillæ (labial palpus); 12, compound eye; 13, position of ocellus; 14, femur of first leg; 15, femur of second leg; 16, femur of third leg; 17, anterior wing; 18, posterior wing; 19, auditory sac; 20, spiracle on mesothorax; 21, spiracle on first somite of abdomen; 22, spiracle on second somite of abdomen accessory organs, the *salivary glands* (Fig. 3, 14) and *gastric cæca* (gastric, pertaining to the stomach; cæca, pl. of cæcum, a pouch or cavity open only at one end, Fig. 3, 15, 16).

The alimentary canal is a long tube extending through the body and variously modified in the course of its extent. The first division is the *mouth*, guarded on each side by the laterally moving mandibles. Between the mandibles, and arising from the inner side of the labium, is a short brown, tongue-like organ, the *hypopharynx* (Fig. 3, 12; Fig. 1, 3). At the base of the hypopharynx opens the tube from the several pairs of salivary glands. A portion of the slightly convex surface of the inner side of the labrum is the *epipharynx*, the seat of the sense of taste.

Beyond the mouth the alimentary canal continues as a short curved *œsophagus* (Fig. 3, 13), which leads to a large *crop*, armed with rows of spine-like teeth. Posterior to the crop is a very small *gizzard*, also furnished with spines, opening directly into a large, thin-walled *stomach* (Fig. 3, 17). At the anterior end of the stomach are attached the six tubular gastric cæca, closed at one end but opening into the stomach at the other. Beyond the stomach the alimentary canal continues as a slightly coiled tube, the *intestine* (Fig. 3, 19), and ends dorsally at the *anal opening* (Fig. 3, 20).

The functions of these different parts are as follows. The food, after being crushed by the mandibles and moistened by the saliva, enters the crop, where it is subjected to the action not only of the saliva but also of a fluid from the gastric cæca. The "molasses" thrown out from the mouth as a defensive fluid by the locust, when handled, consists of partially digested food from the crop, mixed with the digestive fluids. When sufficiently dissolved and changed chemically, the food filters through the spines of the gizzard into the stomach, where it is further acted upon by another digestive fluid. The thin walls of the stomach allow the particles of prepared food to pass through and mingle with the blood in the general body-cavity. This process is called absorption. The anterior part of the intestine is thin-walled, and absorption may take place there and also in the cæca. The unused food-material is removed from the body by means of the anal opening.

The Circulatory System. When the food has been acted upon by the various digestive fluids, and so changed that it may be used to supply the different organs with nourishment, it is distributed over the body by the circulatory system. At the same time certain waste matters are taken away and carried to organs the function of which is to remove them from the body. In the case of man and many other animals, the circulatory system is also the means by which oxygen is carried to all the organs; but, as we shall see in a moment, this work is otherwise provided for in the locust. As soon as the prepared food has been absorbed by the walls of the stomach and intestine it mingles with the blood, which flows through the body-cavity in sinuses (spaces between the various organs), though not in definite blood-vessels. The blood is propelled by a tubular, pulsating vessel, or *heart* (Fig. 3, 21), which extends through the abdomen just beneath the dorsal surface. On account of its position in the body it is often spoken of as the *dorsal vessel*. The heart is prolonged anteriorly into a tube leading to the head, and is partially divided by valves into eight chambers, which permit the movement of the blood only from the posterior to the anterior end. When the blood has been passed out into the general body-cavity it returns through a closed tube (*ventral sinus*) between the muscle masses lying in the lower (ventral) part of the body, and reënters the heart through side openings.

The Respiratory System. The function of the respiratory system is to provide for a constant supply of oxygen for all the organs of the body. This is accomplished by a system of tubes, called *tracheæ*, communicating with the surface by the spiracles of the thorax and abdomen. The tracheæ are connected and form a network of tubes running to all parts of the body, even out into the legs and wings. They are also in connection with a system of large *air-sacs* (Fig. 3, 22, 23) extending through the body. The tracheæ are kept permanently open by a spiral thickening of their chitinous lining, so that air may enter freely at all times. The completeness of the respiratory system in the locust is in striking contrast to the undeveloped character of the circulatory system.

The Excretory System. The union of the oxygen taken in during respiration with the carbon in the body produces carbon dioxide,—a waste product. This leads us to consider the organs which assist in the removal of materials which have helped to build up the body-substance and have become so changed chemically that they are no longer useful. Such organs are termed organs of excretion. Besides carbon dioxide, important excretory products are water and various substances containing nitrogen, hence called nitrogenous wastes. The two latter classes correspond to the material removed by the kidneys of the higher animals.

Very little is known of the process of excretion in insects. It has been generally believed that the carbon dioxide finds its way to the surface through the tracheæ. In some cases it probably escapes through the skin. Water and the nitrogenous wastes are removed by *malpighian tubes* (Fig. 3, 18), which form so prominent an object when the body of the locust is first opened. They ramify through the body-cavity and open into the alimentary canal at the junction of the stomach and intestine, their contents passing to the outside with the undigested food in the intestine. This undigested food is not an excretion, using the word in the sense defined above, since it has never formed a part of the body-substance. It has been suggested that as the chitinous covering of insects is largely made up of carbon and nitrogen, the frequent

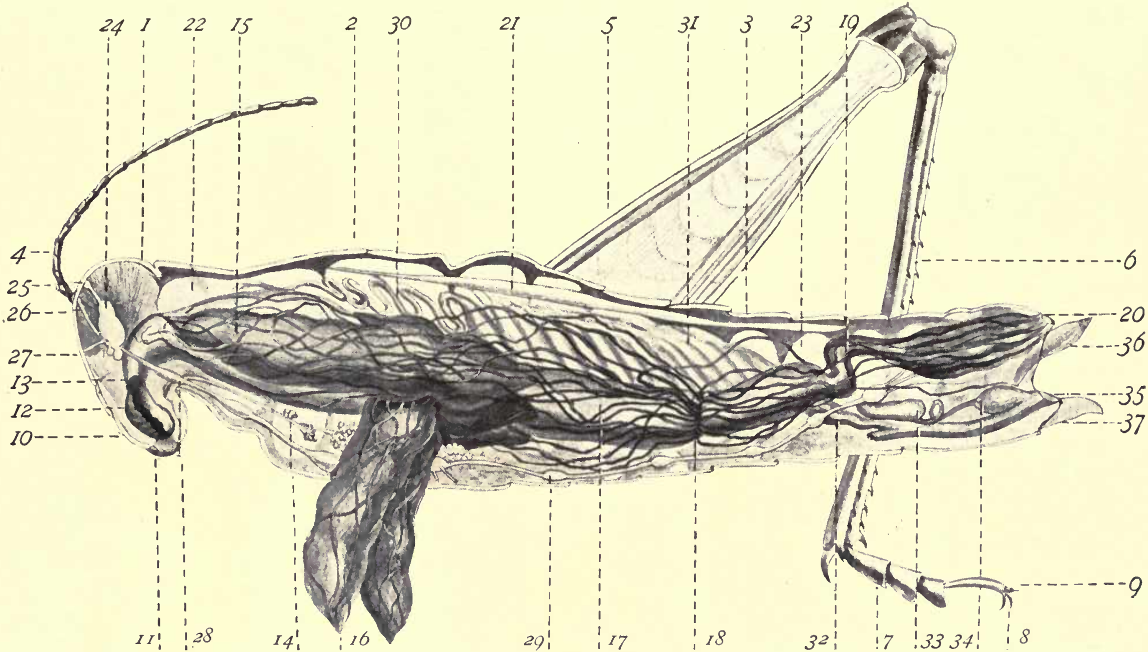


FIG. 3. Dissection of the Common Red-Legged Locust (*Melanoplus femur-rubrum*). × 4

1, head; 2, thorax; 3, abdomen; 4. antenna; 5, femur of third pair of legs; 6. tibia; 7, first joint of tarsus; 8, claw; 9, pulvillus; 10, labrum; 11, mandible; 12, hypopharynx; 13, œsophagus; 14. salivary glands; 15, gastric cæca; 16, gastric cæca; 17, stomach; 18, malpighian tubes; 19, intestine; 20, anal opening; 21, heart; 22, thoracic air-sac; 23, abdominal air-sac; 24, supraœsophageal ganglion; 25, ocellus; 26, nerve leading to antenna; 27, ocellus; 28, subœsophageal ganglion; 29, first abdominal ganglion; 30, ovary; 31, ovary; 32, oviduct; 33, colleterial gland; 34, bursa copulatrix; 35, opening of oviduct; 36, ovipositor; 37, ovipositor casting of the skin (molting) may be an act of excretion of considerable importance.

The Nervous System. All the processes just described, even the flow of blood and the secretion (formation) of the digestive fluids, are under the control of the nervous system. Through its organs of sense the locust is brought into touch with the outside world; by its control over the muscles, movements are made. The nervous system of the locust consists of a series of connected nerve centers, called *ganglia* (Fig. 3, 24, 28, 29), from which *nerves* are given off to the different parts of the body. There are two kinds of nerves, sensory and motor; the former carry messages from the various sense-organs to the ganglia; the latter carry impulses from the ganglia, which result in the contraction of muscles and movements of the various organs, or of the body as a whole.

The largest ganglion is in the head, and is generally called the "brain," or, because of its position just above the œsophagus, the *supraœsophageal ganglion* (Fig. 3, 24). From this ganglion pass the nerves which go to the eyes, antennæ, and labrum. Two cords encircling the œsophagus pass to the next ganglion, which, owing to its position just beneath the œsophagus, is called the *subœsophageal ganglion* (Fig. 3, 28). This ganglion sends nerves to the mandibles and maxillæ. Both the supraœsophageal and the subœsophageal ganglia are the seat of will in the locust, and preside over and coördinate the various general movements of the locust's body. It has been shown that an insect may live for months with the anterior of these ganglia destroyed, if the other is not injured. The insect will feed if food is placed to its mouth, but it loses the power to go in search of food. Of the other ganglia three are in the thorax and five are in the abdomen, forming a median chain resting on the ventral surface of the body-cavity. These ganglia are centers for movements and respiration in the somites to which they belong.

The Muscular System. All the *muscles* of the body are supplied with microscopic nerves. The muscles are attached to the hard covering of the body, and when stimulated by the nervous system they contract, thus moving the part to which they are attached. Though delicate in appearance the muscles are in reality very strong, as may be understood when the activity of the insect is considered.

The Reproductive System. As in most other animals, the union of two dissimilar elements is necessary for the production of a new locust. These elements are the very small, active *sperm-cells* produced by the male, and the larger, passive *egg-cell* produced by the female. On the union of these two cells the egg-cell is said to be fertilized and the growth of a new individual is begun. Occupying a considerable part of the posterior portion of the abdomen of the female are the *ovaries* (Fig. 3, 30, 31), two sets of delicate tubular organs in which the egg-cells are developed. These are connected with the surface by the egg-tube, or *oviduct* (Fig. 3, 32). In the male the sperm-cells are secreted in glands called *spermaries*,

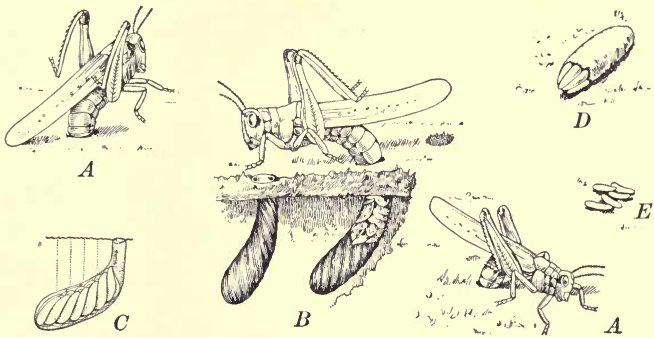


Fig. 4. Rocky Mountain Locust Laying Eggs. About natural size. (After Riley)

A, *B*, female laying eggs; *C*, diagram showing the arrangement of eggs in the hole; *D*, mass of eggs removed from hole and part of covering taken away; *E*, few eggs separated which form a tubular mass in the third, fourth, and fifth abdominal somites. After fertilization the eggs are covered on the way down the egg-tube by a sticky substance poured out from the *cement* or *colleterial gland* (Fig. 3, 33). This gland opens into a capacious pouch (*bursa copulatrix*, Fig. 3, 34), which rests on and opens directly into the oviduct.

Development. The eggs of the red-legged locust are laid in the autumn in holes made by the ovipositor of the female, in the ground of fields, pastures, and waysides. They differ in no important respect from the eggs of the Rocky Mountain locust shown in Fig. 4. Each hole contains from twenty to thirty-five eggs. A secretion from the gland already mentioned binds all the eggs in a single hole into one mass, and when the number is completed more fluid is poured out, which hardens into a firm covering. Here they remain over the winter and hatch out into young locusts in the spring, quite closely

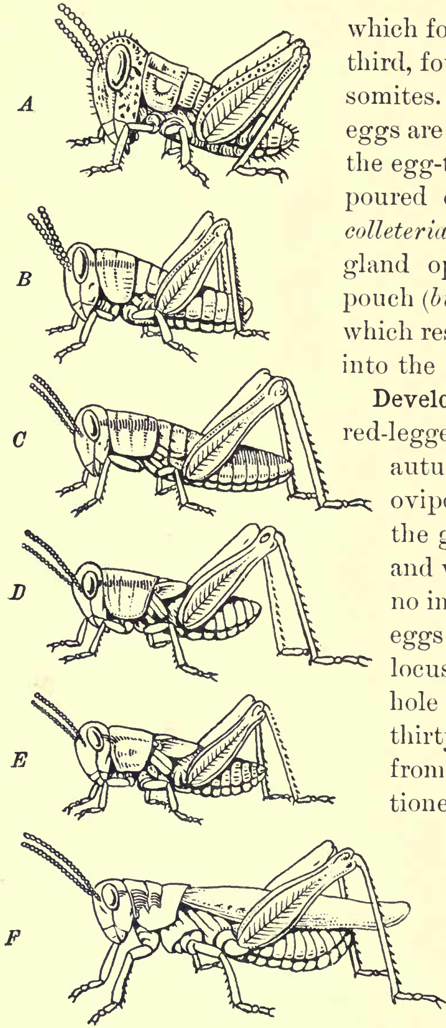


Fig. 5. Development of Locust

A, B, C, D, E, F, stages from nymph to adult, enlarged: *A* × 6, *B* × 2, the others slightly enlarged

(From Packard's *Text-Book of Entomology*) resembling the adult except in absolute and relative size of parts and in the absence of wings. They grow rapidly, molting several times during the summer, appearing each time a little larger and with more fully developed wings. While these changes are going on the young locust is called a *nymph* (Fig. 5, *A–E*). When ready for the last molt, which takes place late in the summer, the nymph climbs up some grass stem or similar object, and, taking firm hold, often with its head pointing downward, remains motionless for several hours, till the skin swells over the head and thorax and finally splits open along a median dorsal line. From this old skin the new head, thorax, legs, wings, and

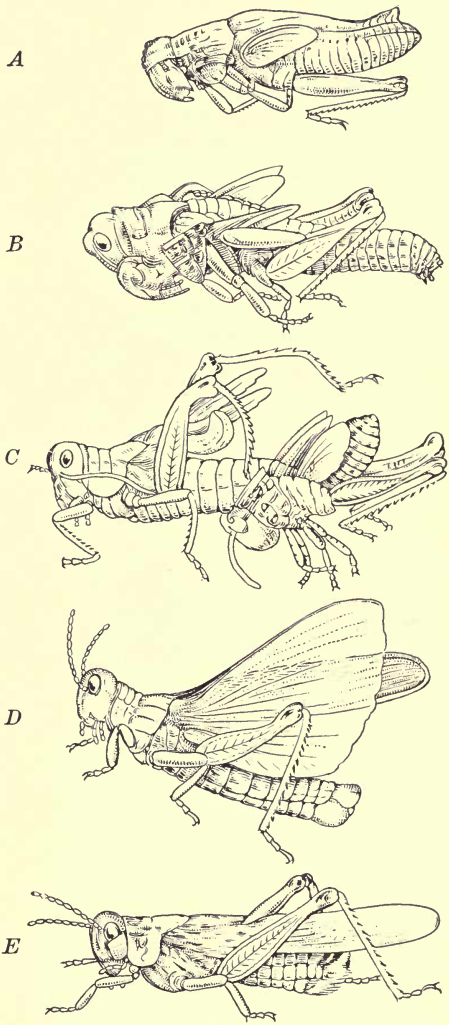


Fig. 6. The Molting of Locust. Slightly enlarged. (After Riley)

A, B, C, D, E, successive stages in the process of molting abdomen are slowly withdrawn while soft, expanding and hardening within half or three quarters of an hour (Fig. 6). It is now a perfect insect, or *imago*, of full size and with fully developed wings. After the females have laid their eggs in the fall most of the locusts die.

Relation to Environment. Red-legged locusts are found in meadows, pastures, fields, and along roadsides, though most abundant where the vegetation is succulent. Specimens from low, damp ground are usually somewhat darker in color than those from high, dry areas. Their food consists of the leaves of grasses and other vegetation. The strength of the mandibles and the complexity of the digestive system fit them admirably for a life of constant forage. Their color is, to a certain extent, protective, for they are not easily seen among the dried grasses of the summer.

Locusts have, when adult, a choice of three methods of progression,—walking, jumping, and flying. The many spines pointing downward on the legs and the pulvilli between the tarsal claws make climbing an easy matter. The complicated system of air-sacs tends to reduce the weight of the body in flight. By means of the air-sacs and wings the locust has solved the problem of aërial locomotion.

The list of the locust's enemies is long and formidable, even if man is not considered. Small animals, such as moles and birds, especially the crow and blackbird, feed on the eggs and young. Some species of wasps use the nymphs to provision their nests, first stinging them to render them helpless. They are also subject to a disease caused by a fungous growth, and may often be found firmly attached to some grass-blade to which they have clung before death. That they have been able to maintain themselves in such large numbers in spite of all their enemies marks them as successful competitors in the struggle for existence.

CHAPTER II

THE ALLIES OF THE RED-LEGGED LOCUST: ORTHOPTERA

The poetry of nature is never dead:
When all the birds are faint with the hot sun,
And hide in cooling trees, a voice will run
From hedge to hedge about the new-mown mead:
That is the grasshopper's, — he takes the lead
In summer luxury, — he has never done
With his delights. — KEATS.

Locusts. Though the common red-legged locust is widely distributed throughout the United States, it has not attracted so much attention as the Rocky Mountain locust, for its effects on agriculture have not been so marked. The latter has the remarkable habit of migrating from its habitat (see map, p. 17) on the dry plains east of the Rocky Mountains, destroying in a few hours the labors of the farmer for several months. Not only are growing crops devoured, but every green thing is attacked, leaving the country as bare as if a fire had swept over it. It has been said that these swarms occur at intervals of about eleven years. The locusts show a tendency to become gregarious (having the habit of associating in groups) from the beginning of their life as nymphs, but their migrations are not generally begun before they are at least half grown. These hordes proved so destructive to the agricultural district of the Middle West from 1873 to 1877 that a commission was appointed by the government to study their habits and to report upon ways and means for checking their devastations. Of late years this species has not been so abundant or so destructive. Many machines have been constructed to capture them. A recent method of fighting them is to cultivate in a sweet solution a fungous growth which destroys them. Members of the swarm are then captured, dipped in the solution, and turned loose, thus spreading the disease. The lesser locust has at various times caused considerable damage to growing crops by appearing at different points in the New England states.

There are several species of migratory locusts in the Old World whose visitations in the past have been most destructive, especially in Egypt, Palestine, Syria, Asia Minor, China, France, Russia, and Germany. They have appeared in almost incredible numbers in certain years, so that a swarm has been estimated to cover two thousand square miles of territory. The prophet Joel has described the onslaught of locusts in the lines beginning, —

> A day of darkness and of gloominess, a day of clouds and of thick darkness, as the morning spread upon the mountains: a great people and a strong; there hath not been ever the like, neither shall be any more after it, even to the years of many generations. — JOEL II: 2.

It is easy to appreciate the fact that in thickly settled areas famine and pestilence may follow the visitation of these insects. Out of the twelve hundred or fifteen hundred species of locusts in the world, only about twelve have the habit of migration to any great extent, and these are mostly species which live on large, elevated, open tracts of desert or semidesert character, where the climate is dry and hot, — for example, such regions as the steppes about the Caspian Sea. Perhaps the determining factor in the migration is excessive multiplication and the consequent need for new feeding-ground.

Many locusts produce sounds by rubbing the inner edge of the posterior femur against the outer edge of the first pair of wings. It is supposed that this is done only by the males, though it may be possible that the females produce sounds which we are unable to hear. Some locusts produce a noise in flight by the friction of the wings.

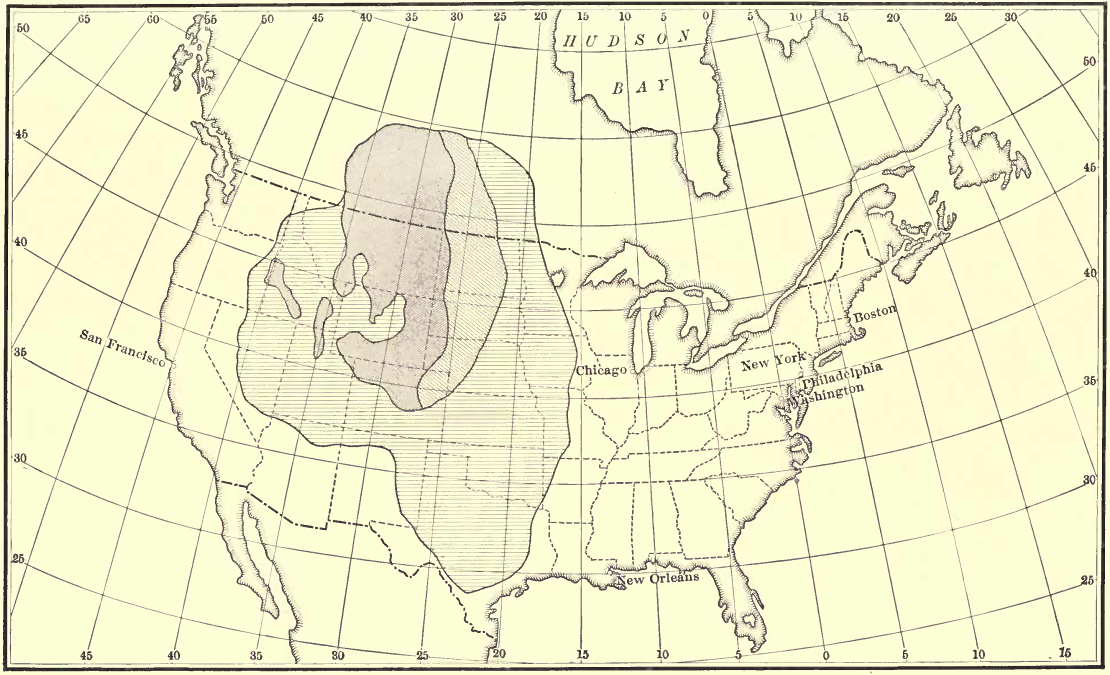


FIG. 7. Map showing Permanent, Subpermanent, and Temporary Habitat of the Rocky Mountain Locust. (After Riley)

Locusts have been and are used to-day as food in various parts of the East. The records on the bricks of Babylon and Nineveh show that they were known in early times as food, and they are mentioned among the clean meats in Leviticus xi. 22. They are in common use among the Arabs and the Bushmen; our own Rocky Mountain locust has been eaten and pronounced quite palatable.

Grasshoppers. The insects which so far we have been considering, while often spoken of as grasshoppers, are not true

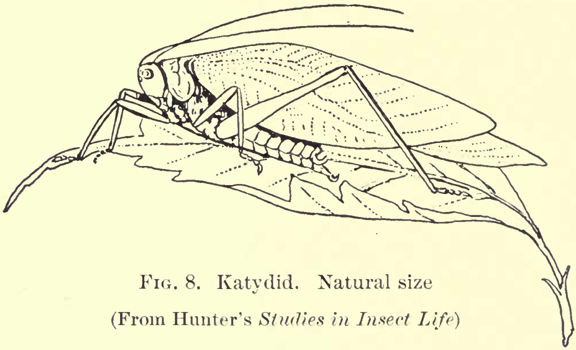


Fig. 8. Katydid. Natural size

(From Hunter's *Studies in Insect Life*)

grasshoppers, though closely allied to them. The locusts have short, rather stout, antennæ, while the true grasshoppers have thread-like antennæ, much longer than the body. Perhaps the most interesting of the grasshoppers are the katydids (Fig. 8), large green insects of arboreal (tree-dwelling) habits, found in the eastern and central United States. They afford an illustration of *protective resemblance*, — a term which is used to cover those cases in which an animal possesses colors or shape which harmonize with its environment (surroundings), or with some particular object in the environment, thus affording protection against enemies. In the case of katydids the whole body is green and the wings are thin and veined like a leaf. The well-known note from which the name "katydid" is derived is produced only by the male, and is made by rubbing the base of one of the first pair of wings against the other anterior wing. An auditory apparatus is found in both sexes at the base of the front tibiæ.

Some of the grasshoppers have taken to a cave life, and are blind and wingless. Color has not been developed, and the insects have the white appearance of plants grown in the dark. The antennæ and legs are elongated to an enormous extent, and must be useful in an environment where much depends on the sense of touch.

Crickets. The crickets (Fig. 9, *A*) resemble the grasshoppers in the possession of long, slender antennæ, but differ from them in having the anterior wings overlapping, instead of meeting in a ridge along the median line of the back. They are widely distributed over the earth, and are, as a

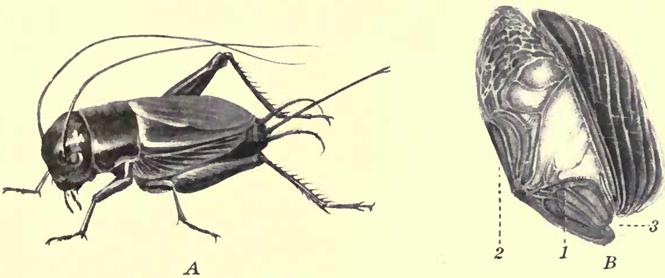


Fig. 9. Cricket

A, female, natural size. *B*, under surface of right wing of male, enlarged: 1, rasp; 2, position of scraper, only the scraper of left wing used; 3, attachment of wing

rule, nocturnal in their habits. They feed mostly on vegetable matter. Our native species live in the fields beneath sticks and stones. Of late years the house-cricket of Europe (*Gryl'lus domes'ticus*) has become common in the cities of the eastern United States. This is the species famous in song and story. Its well-known chirp is made only by the male. The principal vein on the ventral surface of each anterior wing is thickened into a rasp-like structure (Fig. 9, *B*, 1); on another part is a hardened portion called the scraper (Fig. 9, *B*, 2). The noise is produced by raising the anterior wings and rubbing the rasp of the right wing against the scraper of the left. Fig. 9 shows one of the species common in the eastern United States.

FIG. 10. Mole-Cricket. Slightly enlarged

The mole-crickets (*Gryllotal'pa*, Fig. 10) are burrowing insects, which show interesting adaptations to subterranean life. The fore legs are thickened and adapted to burrowing. Roots are easily cut in two by means of a shear-like motion of the joints of each front tarsus against the teeth of the tibia of that leg. For this reason mole-crickets, when numerous, are sometimes a serious pest. The female mole-cricket watches over her eggs and, when they are hatched, feeds the young till the first molt. Mole-crickets are found both in America and Europe.

Cockroaches. The cockroaches are cosmopolitan forms, some of which infest our houses, where they feed on both animal and vegetable matter. They are dark-colored, flattened insects, which depend upon their legs for escape, although most of them possess wings. Their flattened bodies make it easy for them to hide in crevices, whence they come out at night to feed. The female carries her eggs about with her in a large case till the young are nearly ready to appear. It has been asserted of some species that the mother assists the young in escaping from the egg-case. Just before hatching, the distance between the lateral surfaces of the young cockroach is only one third of the diameter from the dorsal to the ventral surface. Soon after hatching, it assumes the dorso-ventral flattened form of the adult, — an adaptation to their life in concealed places. Fig. 11 shows the German cockroach, or "croton-bug" (*Phyllodro'mia german'ica*), with its egg-case; and a larger species, the so-called Oriental cockroach (*Stilop'yga orien'talis*), though there is little evidence to show its original home.

Walking-Sticks. The peculiar insects called walking-sticks are also related to the locusts. Among them are some of the most remarkable illustrations of protective resemblance known in the animal kingdom. The common species in the eastern United States (*Diapherom'era femora'ta*) is shown in Fig. 12. The body and legs are elongated to such an extent that when at rest the resemblance to a twig is most

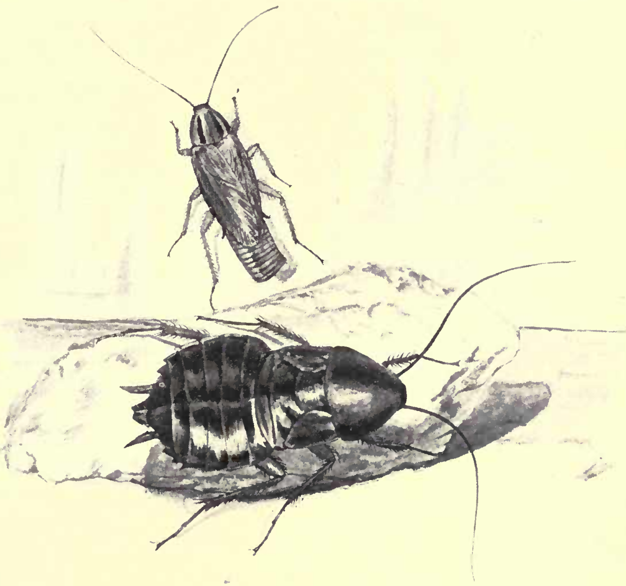


Fig. 11. Cockroaches. Natural size

striking. The insect undergoes a seasonal change of color, being brown when first hatched, turning green after feeding, and changing to brown again as the season advances. It has the power of replacing broken appendages at the next molt, the portion reappearing either as a short stump or as a smaller appendage, complete except for the absence of one tarsal joint. This walking-stick is a voracious feeder on the leaves of trees; it has been known to eat a piece of leaf an inch long and a third of an inch wide in an hour.

Closely related to the walking-sticks are the peculiar East Indian insects known as walking-leaves. In these insects the anterior wings of the female are green and veined like a leaf. The people in the countries where they are found believe that these insects are really transformed leaves. The males are entirely different from the females, having anterior wings which have no leaf-like appearance.

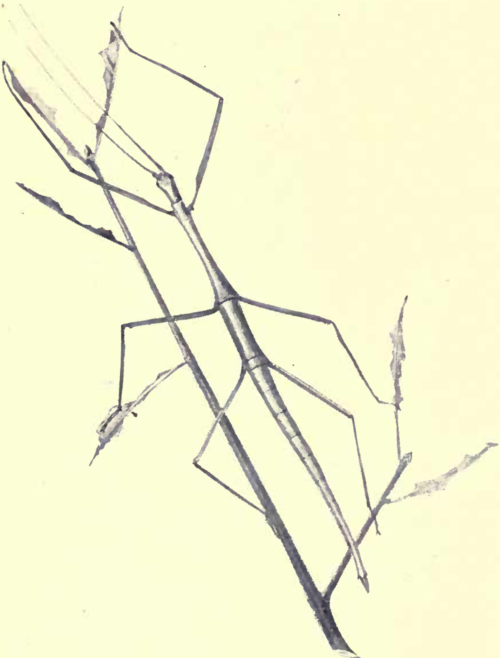


Fig. 12. Walking-Stick. × $\frac{2}{3}$

Mantids. The mantids are remarkable for the development of the fore legs, which are unusually large and strong and armed with stout spines. The function of these legs is to seize and hold living prey, which consists of other insects. When lying in wait the fore legs are held up in the air, but when an insect comes within reach they are extended with swiftness and precision. The eggs of the mantids are deposited in a mass of foam-like matter, which the female discharges from the tip of the abdomen. This material soon hardens and forms a protecting case for the eggs. The mantid

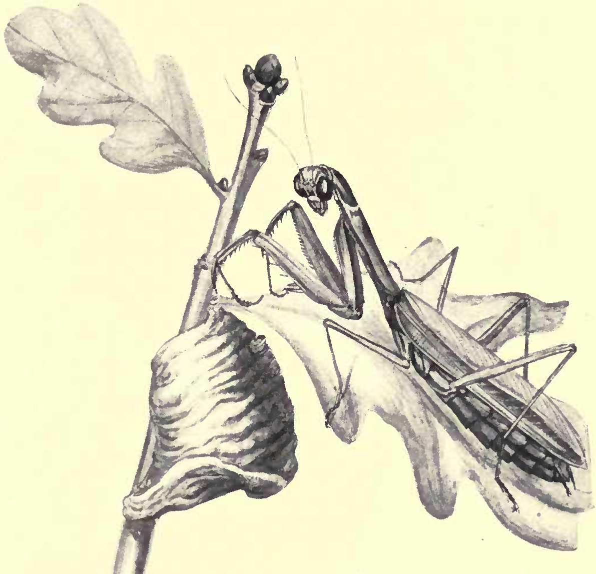


FIG. 13. Japanese Mantid. Natural size

shown with its egg-case in Fig. 13 is a Japanese species (*Tinode'ra sinen'sis*), which has recently been introduced in a few places in the eastern United States. The color is brown and is to some extent protective, and as this inconspicuous coloration may render it easier for the insect to approach its prey or to escape notice while waiting for food, it may be classed as an example of *aggressive resemblance*, which term covers those cases where an animal, in resembling its immediate environment, either in shape or color, or both, is thought thereby to be assisted in attack on its prey.

Several species of mantids from India resemble different flowers which are visited by insects, and seize upon such unwary visitors as do not detect the imposition. In this case the resemblance is to an object attractive to the prey, and may be spoken of as *alluring coloration.* Dr. J. Anderson showed specimens of one of these insects to members of the Asiatic Society of Bengal in 1877, and communicated information concerning them as follows. "On looking at the insects from above, they did not exhibit any very striking features beyond the leaf-like expansion of the prothorax and the foliaceous appendages to the limbs, both of which, like the upper surface of the insect, are colored green; but on turning to the under surface the aspect is entirely different. The leaf-like expansion of the prothorax, instead of being green, is a clear, pale lavender violet, with a faint pink bloom along the edges of the leaf, so that a portion of the insect has the exact appearance of the corolla of a plant, — a floral simulation which is perfected by the presence of a dark, blackish-brown spot in the center over the prothorax, and which mimics the opening to the tube of a corolla. A favorite position of this insect is to hang head downwards among a mass of green foliage; and when it does so it generally remains almost motionless, but at intervals evinces a swaying movement, as of a flower touched by a gentle breeze."

Definition of Orthoptera (Gr. *orthos*, straight; *pteron*, wing). All the insects mentioned in this chapter have the mouth-parts adapted to biting, and most of them have two pairs of wings. The posterior wings, when present, are folded lengthwise like a fan beneath the hardened anterior wings, and are thus protected from injury. These insects agree in their mode of growth, which is a gradual increase of size by successive molts, without any abrupt change of form. The imagoes differ from the nymphs chiefly by their larger size and the presence of wings. On account of these common characteristics these insects are united in a group, or *order*, called *Orthop'tera*, in allusion to the longitudinal folding of the posterior pair of wings.

CHAPTER III

THE MAY-FLIES (PLECTOPTERA) AND THE DRAGON-FLIES (ODONATA)

The sun comes forth and many reptiles spawn;
He sets and each ephemeral insect then
Is gathered into death without a dawn,
And the immortal stars awake again. — SHELLEY.

May-Flies. The May-flies (Fig. 14), which stand in literature as the type of brief and purposeless existence, are delicately constructed, pale insects, with usually four finely veined wings and two or three long white filaments projecting from the end of the abdomen. The eyes are comparatively large, but the mouth-parts are so reduced that no food can be taken during adult life, which in most species lasts only a few hours. May-flies appear in countless numbers in late spring or early summer, dance about in the air at dusk in swarms so dense that the atmosphere seems one mass of moving forms, and, after laying their eggs, perish with the day, forming a great food-supply for fishes and birds.

The eggs are laid in the water and hatch into nymphs (*Ephem'era*, Fig. 14), which do not at all resemble the adult, and are adapted to an aquatic existence by the presence, along the sides of the abdomen, of outgrowths of the body-wall penetrated by tracheæ. These outgrowths are called *tracheal gills.* The delicate skin of which the gills are formed permits the passage of oxygen from the surrounding water inward, and allows the escape of carbon dioxide gas. The posterior division of the heart (or an accessory chamber) is so arranged that it propels blood backward into the abdominal filaments, so that they, too, act as an organ of respiration. The young feed on small aquatic animals, or on plants. After a year or more of this life beneath the surface, during that time undergoing many molts, the nymph develops rudimentary wings. From the nymph issues a winged form which may be called a *subimago.* Within a very short time the skin is again cast, even to a thin covering from the wings, and the true imago comes forth. A molt in the winged state is known nowhere else among insects. Though the reduced mouth-parts make it impossible for the adult May-fly to take any food, the alimentary canal is not useless. Air is

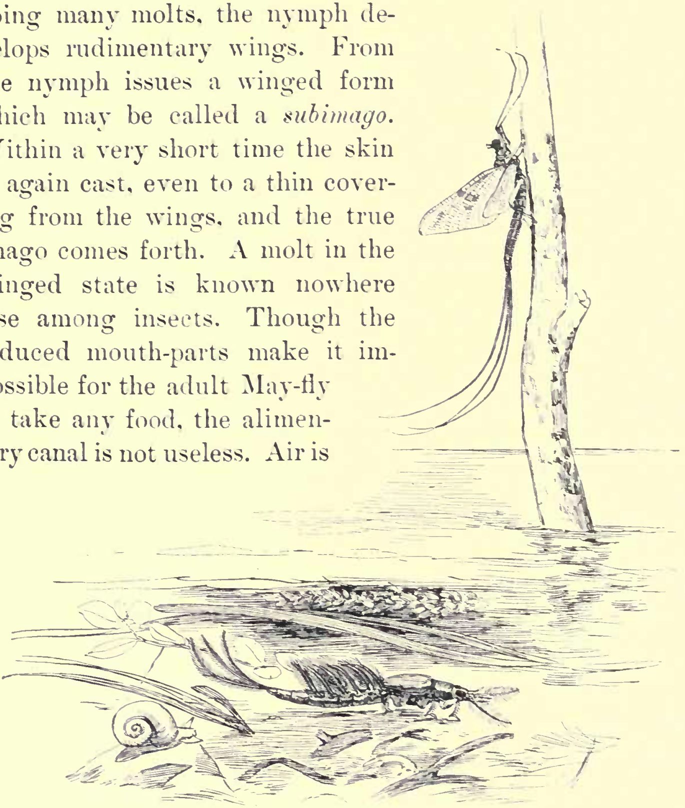


FIG. 14. Nymph and Imago of May-Fly. Natural size

taken in at the mouth, and the capacious stomach acts as a balloon, being provided with valves so that the air cannot escape.

Definition of Plectoptera (Gr. *plektos*, twisted; *pteron*, wing). The May-flies make up the order *Plectop'tera*. The Plectoptera may be distinguished from other insects by the reduced mouth-parts, the great disproportion in the size of the anterior and posterior wings, and by the presence of abdominal filaments. From the earliest nymph stage to the imago there is quite a clearly marked though gradual change of form, or *metamorphosis*.

> To-day I saw the dragon-fly
> Come from the wells where he did lie.
> An inner impulse rent the veil
> Of his old husk : from head to tail
> Came out clear plates of sapphire mail.
> He dried his wings : like gauze they grew ;
> Thro' crofts and pastures wet with dew
> A living flash of light he flew. — TENNYSON.

Dragon-Flies. The dragon-flies (*Libel'lula*, Fig. 15) are familiar insects found flying over the surface of still or running water. They feed on other insects, which they capture on the wing. They are lovers of the sunshine, and are most active in the brightest and hottest part of the day. The larger kinds hawk freely over the surface of the water at some distance above it, often far out from the shore, where their range of vision is unobstructed ; while the smaller and weaker kinds keep closer to the shore and the protection of vegetation. All are voracious feeders, destroying large quantities of flies and mosquitoes. Many superstitions have become associated with them in different parts of the country ; in the North it is believed that they sew up the mouths and ears of children ; in the South, that they bring dead snakes to life. It is, perhaps, needless to say that they are harmless. The head is made up almost entirely of the great, staring, compound eyes, which shine like fire as the dragon-fly moves about. The mouth has strong jaws, somewhat resembling the powerful mandibles of the locusts. The wings are large, with many veins, and are moved by powerful muscles ; but the legs are slender and small, as the dragon-flies are preëminently creatures of the air. The long and slender abdomen is used to balance the insect in its headlong flight.

The eggs, generally attached to water plants, hatch into dark-colored, flattened aquatic nymphs. The mouth-parts are unique in structure. The second maxillæ are enlarged and armed with hooks at the extremity. This formidable organ can be extended to seize upon any insect within reach, and when not so engaged it covers the entire face like a mask, giving a peculiar and comical aspect to a front view. The nymphs breathe by means of tracheæ, which line the posterior portion of the alimentary canal. When water is drawn into the canal, air is absorbed from it by this

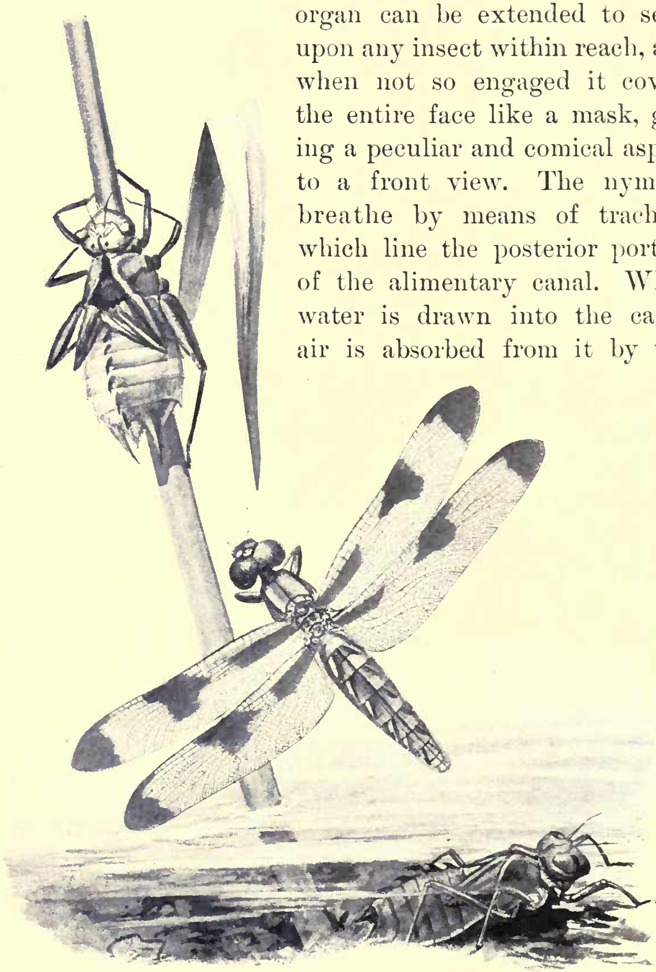


Fig. 15. Metamorphosis of Dragon-Fly. Natural size

system of air-tubes, and water, deprived of its free oxygen, can be ejected violently, thus forcing the nymph forward. After successive molts the nymph develops rudiments of wings, and finally crawls out of the water to some convenient support, when the skin splits down the back and the dragon-fly, with crumpled wings, slowly emerges. A short time elapses before the body hardens and the wings expand, and then the imago flies away to live its short adult life.

There are two quite distinct types of dragon-flies, both widely distributed over the world. The form represented in Fig. 15 is of comparatively robust build. The eyes touch each other along the median line of the head. The posterior wings are broader at the base than the anterior pair, and both pairs are held horizontally when the insect is at rest. To this type belong the best fliers of the group. The insects which illustrate the other type, while they can easily enough be recognized as dragon-flies, are of more slender build. Their eyes are widely separated on opposite sides of the head. The anterior and posterior wings are alike in size and shape, and when not in use are folded against the abdomen. The flight is less sustained and more erratic than with species of the first type. Some of these dragon-flies, notably species from the tropics, are most beautiful both in form and color. The French call these insects "demoiselles," which we may translate damsel-flies.

Definition of Odonata (Gr. *odons* (*odont*), a tooth). The dragon-flies constitute the order *Odona'ta*, a word meaning "toothed," perhaps in allusion to the teeth on the second maxillæ of the larvæ. The Odonata are distinguished by the biting mouth-parts and the four equal or nearly equal net-veined wings. The metamorphosis is fully as well marked as in the preceding order.

CHAPTER IV

THE BUGS: HEMIPTERA

The shy cicada, whose noon-voice rings
So piercing shrill that it almost stings
The sense of hearing. — ELIZABETH A. KERR.

Water-Bugs. In almost every pond and stream, not only in the United States but scattered widely over almost the whole world, are to be found oval gray and black insects, usually a little over a centimeter long (about half an inch). These are water-boatmen (*Corix'a*, Fig. 16, *B*). They have a long beak formed by the union and lengthening of the second maxillæ, inclosing at its base the bristle-like mandibles and first maxillæ. With this they suck the body-fluids of other water-creatures. They are adapted to rapid locomotion in the water by means of the lengthened and fringed middle and hind legs. They breathe a thin film of air, which is caught in the fine hairs which cover the body, making them look as if incased in polished metal. Slight movements of the legs cause currents of water to pass over this air-film, helping to purify it, and rendering frequent visits to the surface unnecessary. When at the surface air

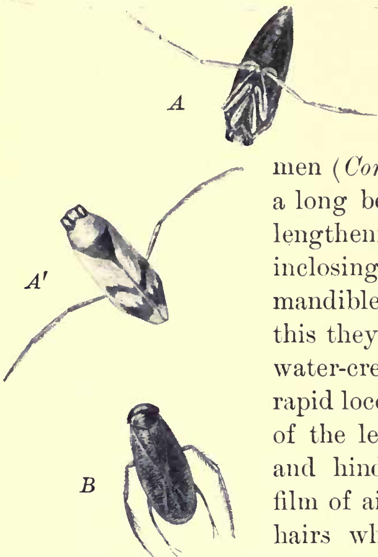


FIG. 16. Back-Swimmers and Water-Boatman. Slightly enlarged

A, Notonecta, ventral view (swimming attitude); *A′*, Notonecta, dorsal surface; *B*, Corixa is taken into a cavity under the wings, where the spiracles are placed, so that quite a supply is on hand at all times. While these insects are thus adapted to water-life, they can fly, and often leave their native element, especially if it is in danger of becoming dry.

Another widely distributed group of insects resembling the foregoing are the back-swimmers (*Notonec'ta*, Fig. 16, *A*, *A'*), which have the curious habit of swimming on their backs, as their common and scientific names denote. A favorite position of these insects is to float with the head down and the tip of the abdomen protruding just enough to admit the passage of air to chambers beneath the wing-covers. The back-swimmers can inflict a momentarily painful wound with their sharp beaks. Search made for these insects will reveal a variety of other beaked forms, some of which live beneath the surface of water, while others skim swiftly over it.

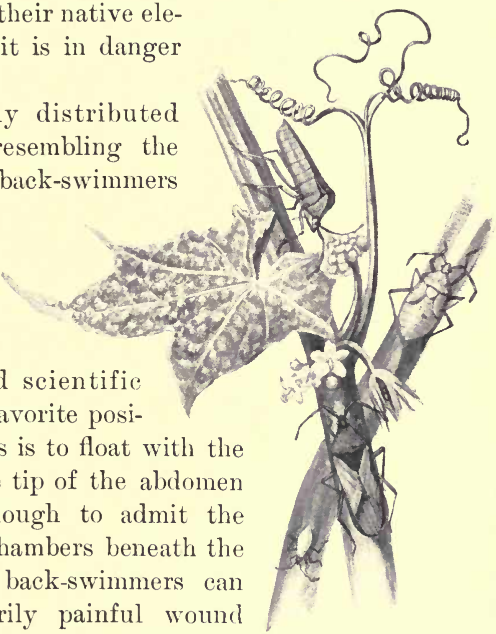


Fig. 17. Squash-Bug and Young. Natural size

Plant-Bugs. The squash-bug (*An'asa tris'tis*, Fig. 17), a well-known enemy of squash and pumpkin vines, also possesses a beak, which is used to suck plant instead of animal fluids. This bug is a little over two centimeters (nearly an inch) long, and brownish black in color. It has the power, in common with many other allied species, of pouring out an evil-smelling secretion from two openings near the base of the middle pair of legs, which probably renders it obnoxious to some creatures which might prey upon it. Observations on the food of birds of the eastern United States seem to show that, so far at least as the birds are concerned, these *repellent odors* are not in all cases entirely effective, since many species of plant-bugs are fed upon quite generally by birds.

Cicadas. An examination of the large, broad-headed, triangular insects known as harvest-flies, or cicadas, will show that they, too, agree with the foregoing insects in the possession of a sucking-beak. There are several species in the United States, of which the best known is the periodical cicada (*Cica'da septen'decim*, Fig. 18), usually, but wrongly, called the thirteen or seventeen year "locust." At the base of the abdomen of the male is a "drum," or sound-producing organ, where a high-pitched note is made by the rapid

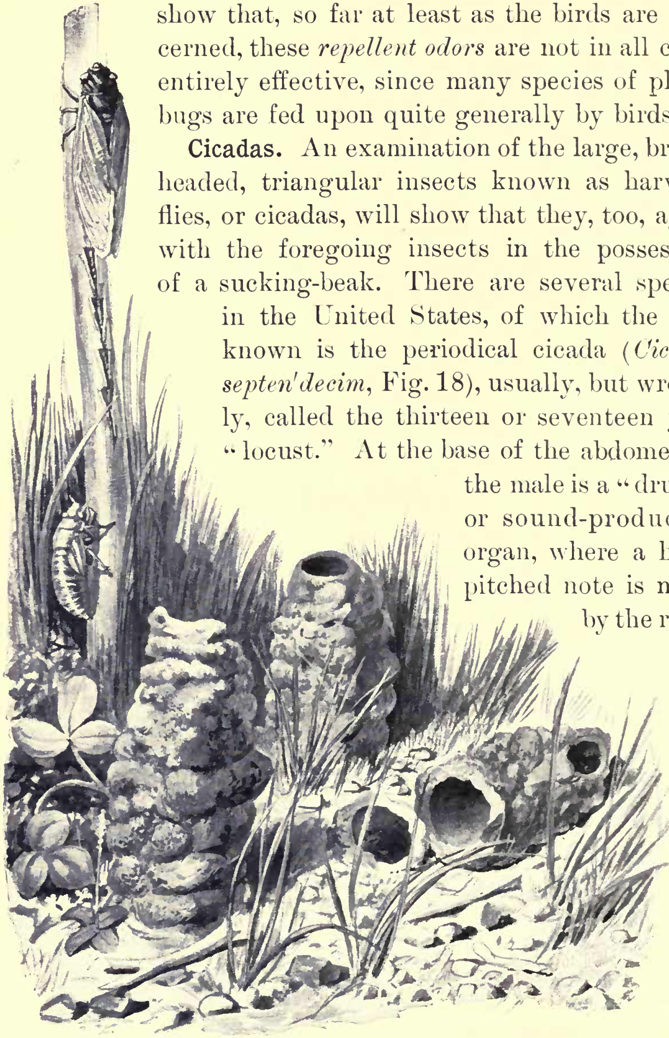


FIG. 18. Periodical Cicada. × ½

vibration of tightly stretched membranes, somewhat in the way sound may be produced by pushing up and down on the bottom of a tin pan. This note, heard in the middle of hot summer days, has been celebrated as the "song" of the cicada since the time of the Greeks.

The female lays her eggs in slits, usually in the small terminal twigs of trees, generally causing them to wither and die. In a year in which these insects appear in large numbers the trees look as if a fire had passed over them and scorched the ends of all the twigs. The eggs hatch in about six weeks, and the nymphs drop to the ground, into which they dig, and for a long period of time, thirteen years in the southern states and seventeen years in the North, they lie in a cell feeding on the juices of the roots of trees. Early in the summer of the thirteenth or seventeenth year, they rise to the surface, and, clinging to some convenient support, cast their last nymph skin to come out as winged creatures for their few weeks of adult life. In some cases, when the nymphs reach the surface, they build peculiar cones of clay (Fig. 18) several inches in height, over the mouths of their burrows, entirely closing the top of the cone. In the upper part of these they wait the period of their final molt. The formation of these structures has been explained by some as due to the prevalence of long-continued wet weather at the time of the emergence; by others, as occasioned by heating of the ground in certain localities by the sun, thus bringing the nymphs to the surface before their time.

Aphids. Every one who has tried to keep plants indoors must have noticed the small green, oval insects known as plant-lice, or aphids. There are many species infesting different plants, upon the juices of which they feed. Some attack the roots, but the greater number are found upon the foliage. They are generally not more than three millimeters (about an eighth of an inch) in length, with a somewhat pear-shaped body, and with or without wings. In most species there is found projecting from the back of the sixth abdominal somite a pair of slender tubes, which secrete a sticky, waxen substance, which is probably protective in its nature. Aphids are sought for by ants for the sake of a sweet substance called "honeydew," poured out from the alimentary canal. We shall see later how certain species of ants have taken to protecting aphids in order to secure a constant supply of this food.

The life-history of some of the aphids is most remarkable. An aphid colony in the summer may consist almost entirely of wingless females, which have the power of producing generation after generation of living young without fertilization. This form of reproduction is known as *parthenogenesis.* The young so produced are females, and many of them are wingless, though winged females are produced which start colonies in other places, sometimes on a different food-plant. Both winged and wingless females are able to produce young parthenogenetically within from ten to twenty days. This kind of reproduction goes on till the approach of cold weather or the failure of the food-supply, when males are produced. After pairing, the female lays eggs which last through the winter and hatch into females in the spring, which start a new colony as already described.

One of the greatest enemies of the grape is an aphid known as *Phylloxe'ra vasta'trix*, which has been the scourge of many vineyards in France. It lives both on the roots and on the leaves. Other species, called woolly aphids, have the power of secreting a white downy substance, which entirely covers their bodies. One of these, which lives in colonies, making white masses on the alder, is known as the alder-blight. This insect secretes honeydew, and is visited by ants.

Scale-Insects. Some of the greatest enemies to the horticulturist are included among the scale-insects, which infest nearly all kinds of fruit-trees and many shade-trees. In some species the body is scale-like in form; in others (*Mytilas'pis*

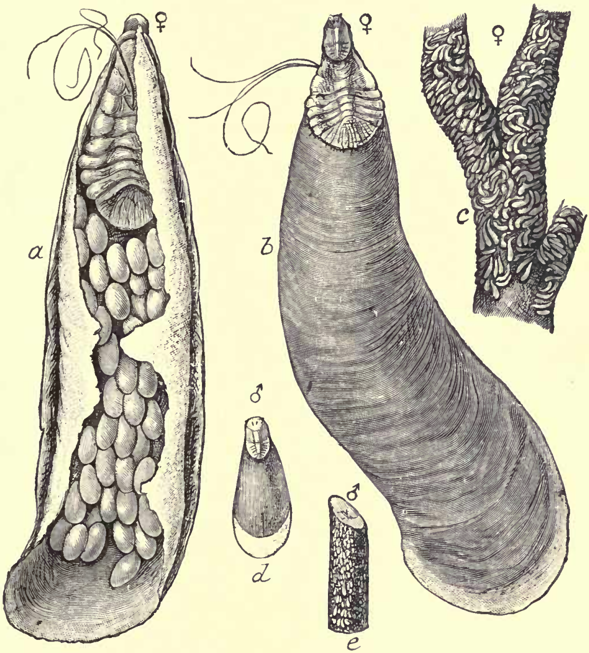


Fig. 19. Scale-Insect. (After Howard, *Year-book*, United States Department of Agriculture, 1894)

a, female, from beneath, showing eggs protected by scale, × 24; *b*, female, from above, × 24; *c*, female scale on branch, natural size; *d*, male scale, × 12; *e*, male scales on twig, natural size

pomo'rum, Fig. 19), the female, which begins life as an active insect, soon settles down, with the beak fixed in the tissues of some plant, and develops a waxy scale as a secretion from the skin of the back, beneath which she lies protected for the remainder of her life. The male is entirely different in appearance and development. At first it resembles the female, but it soon passes into a short resting, or *pupal* stage, beneath a protecting scale, from which it reappears as a two-winged insect with rudimentary mouth-parts. In this form of metamorphosis the young differs greatly from the imago, and there is a resting pupal stage before the emergence of the imago. Following common usage, we may speak of this as a "complete" metamorphosis. The young is called a *larva.*

There are more than eight hundred species of scale-insects known, and it is certain that many more remain to be discovered and described. Man is indebted to these insects for a variety of products of greater or less value. One of the scale-insects (*Coc'cus cac'ti*), found on the cactus in Mexico, is the source of the red coloring matter, cochineal; to another (*Carte'ria lac'ca*), of India, we are indebted for lac. Several species produce waxy substances in use in various countries of the East. The white wax of one Chinese species, formerly much prized, is said to be replaced now by the use of kerosene. The manna mentioned in the Book of Exodus is probably the secretion of a scale-insect. It is a sweet substance used to-day by the Arabs as food.

Definition of Hemiptera (Gr. *hemi*, half; *pteron*, wing). The insects mentioned in this chapter all agree in possessing a sucking-beak. They are the insects to which the word "bug" is strictly applicable. The order is called *Hemip'tera*, the word referring to the fact that in some families the anterior wings are hardened as a protection for about half their length. Outside of the cicadas and scale-insects the Hemiptera develop without marked metamorphosis (see Fig. 17).

CHAPTER V

THE BEETLES: COLEOPTERA

Now fades the glimmering landscape on the sight,
  And all the air a solemn stillness holds;
Save where the beetle wheels his drony flight
  And drowsy tinklings lull the distant folds.

Gray, *Elegy in a Country Churchyard.*

Tiger-Beetles and Ground-Beetles. The tiger-beetles (*Cicinde'la*, Fig. 20) will serve to introduce another type of insect. Tiger-beetles are usually metallic, shining, bright-colored species, about one and a half centimeters in length, with large heads and prominent eyes, and are found on sandy roads or beaches, flying about while the sun shines. Some of them are bright red or green; some are brown or black, with white markings; while others are protectively colored, resembling the sand on which they live. They run swiftly, and when disturbed take flight, only to alight at a short distance, often facing about so that they can better watch the pursuer. The mouth-parts are all well-developed and distinct, as in the locust. The mandibles are long, and toothed on the inner edge, admirably fitted for seizing living prey. The posterior wings are concealed by a pair of hardened wing-covers (anterior wings), which meet in a median longitudinal line down the back. The wing-covers are not used in flight, but serve to protect the delicate wings beneath.

The larvæ are misshapen, dirty-white grubs, living in holes which they dig in sandy places. Two hooks on the dorsal surface enable them to climb up and down in their holes, which are sometimes thirty centimeters or more deep, and prevent their being dragged out when they have hold of their prey. Here, with the earth-colored head even with the surface, they lie in wait, seizing any passing insect with their strong jaws.

Often there is found beneath stones in fields a small blue oval insect, about two centimeters in length, which, when handled, emits a puff of smoke-like gas with a strong odor, and a quite audible noise, as of the report of a tiny pop-gun. This is the bombardier-beetle (*Brach'inus*). Its secretion belongs to the class of repellent odors, and may often render possible the escape of its possessor before the enemy has had time to recover. The bombardier is one of the large family of ground-beetles which are found beneath sticks and stones everywhere. Ground-beetles are generally black in color; most of them capture living prey. Some have taken to cave life and have become blind. In such cases hairs possessing the sense of touch are well developed on the body, so that the beetles run as swiftly as if they possessed eyes.

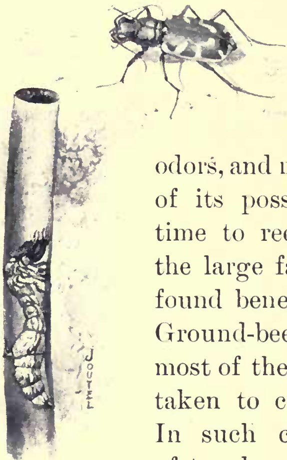


Fig. 20. Tiger-Beetle and Larva. Natural size

Water-Beetles. The whirligig-beetles (*Dineu'tus*, Fig. 21) are familiar, oval insects found in groups

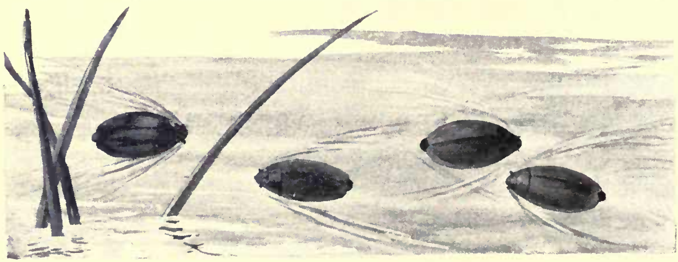


Fig. 21. Whirligig-Beetles. Natural size

circling about on the surface of still water. They can see both below and above the surface of the water, as the two eyes are divided into four, and the parts separated so that watch can be kept for danger from either direction. The whirligigs are protected by a strong-smelling milky secretion which probably renders them distasteful to fishes. They are

Fig. 22. Diving Beetle. Slightly enlarged

able to dive to escape danger, carrying down with them a small supply of air.

Beneath the surface of such ponds and pools as the whirligig-beetles frequent are to be found different species of diving beetles (*Dytis'cus*, Fig. 22), which have adaptations similar to those mentioned among the aquatic Hemiptera. Thus in some the spiracles, which in land insects are along the sides of the abdomen, are here placed beneath the edge of the wing-covers on the back, and the space beneath the wing-covers is used as an air-reservoir, which is replenished with pure air by rising to the surface. In other species a thin coating of air is carried on the under side of the abdomen. This supply is obtained by pushing the head above water and capturing a bubble of air with the antennæ, which are quickly folded beneath the head, carrying the imprisoned bubble to the under surface of the body.

Scavenger-Beetles. A useful part in the economy of nature is played by the scavenger-beetles (*Necroph'orus*, Fig. 23), large black, red-spotted insects, which dig beneath the carcasses of small animals, thus burying them beneath the surface. The female then lays her eggs in the decaying material, upon which the larvæ feed until ready to transform. This exertion removes the carcass from the field of operations of other creatures which might feed upon it, if it were left exposed, and thus destroy the eggs, or larvæ. As these beetles are protected by a fetid odor, their striking markings are usually spoken of as an example of *warning coloration*, a term applied to those appearances in animals which are thought to be useful in notifying enemies of the presence of something disagreeable or dangerous.

Fig. 23. Scavenger-Beetle. Slightly enlarged

Lady-Beetles. The common and well-known insects variously called lady-beetles, lady-bugs, or lady-birds (*Coccinel'la*,

Fig. 24), are hemispherical in shape and generally reddish or yellowish in color, with black spots. Both the imagoes and larvæ of most species feed upon plant-lice and other insects injurious to vegetation; hence they are to be reckoned among the insects useful to the farmer. A few years ago, when the orange-growing industry of California was threatened with great loss, if not total extinction, from the attacks of a scale-insect, an Australian lady-beetle (*Veda'lia*) was introduced to feed upon it. The success of the experiment was so great that large sums have been saved to the orange-growers. Another scale-insect, the San José scale (*Aspidio'tus pernicio'sus*), so called because it first appeared many years ago in that city, has since spread widely over the country, causing great damage to the orchard interests. Investigations set on foot by the Division of Entomology of the United States Department of Agriculture located the original home of the insect in China, and the discovery was made there of a lady-beetle (*Chiloc'orus sim'ilis*) which preys upon it. This lady-beetle has now been introduced and distributed to infested regions, with every prospect of success.

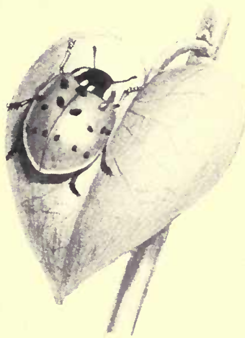


FIG. 24. Lady-Beetle. × 3

The lady-beetles are protected by a yellow, odorous fluid formed in the blood. When the insect is seized the fluid oozes out from the ends of the femora. The bright colors of these insects are usually cited as an example of warning coloration.

Click-beetles. The click-beetles are a well-known group, generally brown in color and of elongate form. The species are able to leap into the air when placed on their backs. The mechanism which makes this possible consists of a spine projecting backward on the ventral surface of the prothorax, and a corresponding cavity on the ventral surface of the mesothorax. When the beetle falls upon its back, as often happens from its habit of dropping to the ground as though dead, the legs are so short that they are unable to help much in regaining its position; then the spine on the prothorax is driven into the cavity of the mesothorax with force sufficient to cause the base of the wing-covers to strike against the surface and throw the beetle into the air. If it lands wrong side up, the act is repeated until success crowns its efforts. The larvæ are called wireworms, and live in decaying wood or attack the roots of vegetables.

Our largest species is called the eyed click-beetle (*A'laus ocula'tus*, Fig. 25), on account of the oval, eye-like spots on the back of the prothorax. These spots have been thought to be of the nature of *terrifying organs.* Professor Needham of Lake Forest University says: "If there be one thing more than another of which animals are suspicious, it is a strange-looking eye. Nature has taken advantage of this fact in protecting some of the most innocent little creatures by developing upon them spots that look like sinister eyes." Several South American and West Indian species of click-beetles have the power of emitting light from spots on the side of the prothorax and abdomen, and are used by the natives as ornaments, being sewed in lace and worn on the head. The light is the most brilliant and continuous of any

Fig. 25. Eyed Click-Beetle. Slightly enlarged

luminous insect, though it is not given off when the insect is at rest or feeding.

Fireflies. The power of giving off light is possessed by the majority of the members of an allied group, the fireflies (*Photu'ris*, Fig. 26), — soft-bodied insects about two or three centimeters in length, dull-colored, and with the prothorax usually margined with red or yellow. The wing-covers are much softer than in other beetles. Fireflies are, for the most part, nocturnal in their habits, clinging to the under side of leaves during the day. They are protected from the insect-eating birds by a strong odor which renders them distasteful. The luminous spots are on various abdominal somites, generally the last. Fireflies appear in greatest numbers in the latitude of the Middle Atlantic states for a week or more in the month of June. Many attempts have been made to account for the light produced by the fireflies. The light-giving organ seems to consist of fat-cells inclosed in a network of fine tracheæ. These cells apparently have the power, under nervous control, of secreting a substance, possibly phosphureted hydrogen, which is luminous when acted upon by the oxygen furnished by the

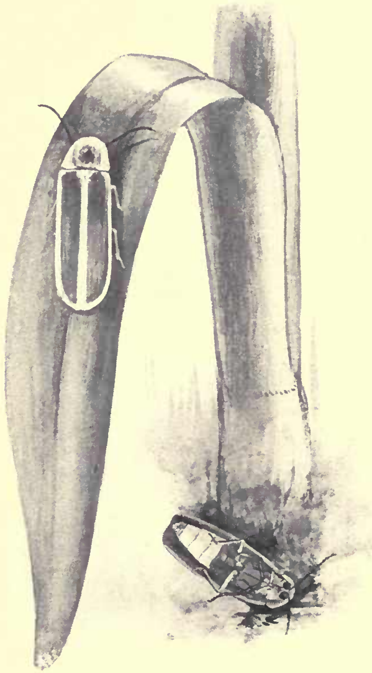


Fig. 26. Firefly. Slightly enlarged

tracheæ. The process is, therefore, a form of oxidation. It is interesting to note that the efficiency of this apparatus as a light-producing organ has been estimated at 100 per cent. In such artificial illumination as a gas-jet, for example, only about two per cent of the radiant energy consists of light-rays. The function of the light of the fireflies is not understood.

Scarabs. Certain beetles of a quite different group have long attracted the attention of observers by their curious habit of forming and rolling about a pellet of manure for food for themselves or their larvæ. We have several species of these beetles in the United States, but the best known of the

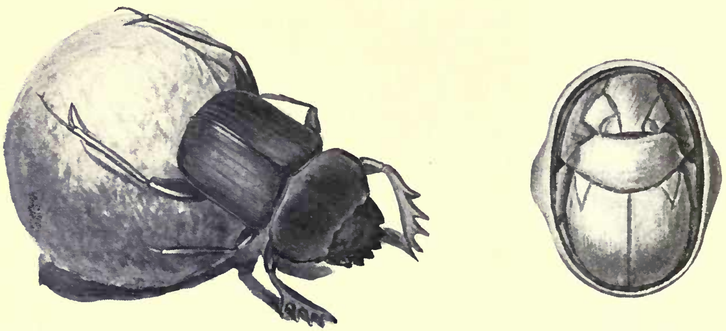


FIG. 27. Sacred Beetle and Scarab in Stone. × 2

group is the sacred beetle of the Egyptians (*Ateu'chus sa'cer*, Fig. 27), the *Scarabæus* of the ancients, figures of which are found carved in stone on the monuments of ancient Egypt. These beetles played an important part in the symbolism of the Egyptians, to whom they typified the world and the sun, — the former on account of their round pellets, the latter on account of the projections on the head, which were likened to the rays of the sun.

To the same group belong our common May-beetles or June-beetles (*Lachnoster'na*, Fig. 28). These beetles live in the ground in the larval stage, feeding on the roots of plants.

The larvæ are the well-known white grubs often turned up by the plow in the spring. The pupal stage is also passed

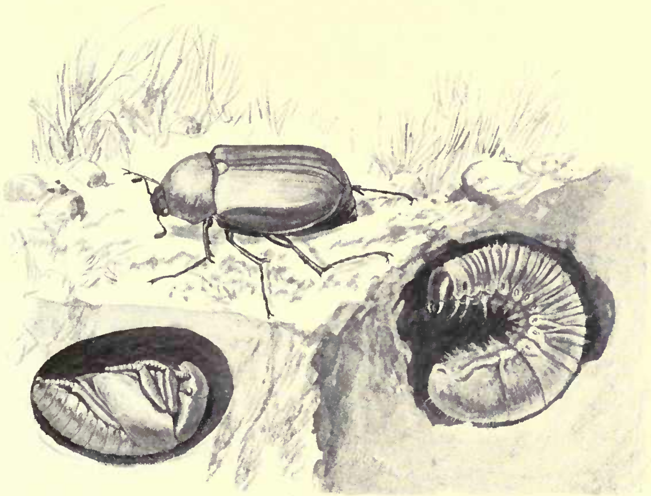


Fig. 28. Metamorphosis of June-Beetle. Natural size

in the ground. The imagoes feed on the leaves of trees, often completely defoliating them.

Definition of Coleoptera (Gr. *koleos*, sheath; *pteron*, wing). The insects which we have considered in this chapter agree in possessing biting mouth-parts and hardened sheaths to cover the posterior wings. They are termed beetles, or *Coleop'tera.* The Coleoptera undergo a "complete" metamorphosis; their larvæ are called grubs.

CHAPTER VI

THE BUTTERFLIES AND MOTHS: LEPIDOPTERA

And what 's a butterfly? At best
He 's but a caterpillar drest. — JOHN GAY.

The Monarch Butterfly. One of the commonest and best known of our butterflies is the monarch, or milkweed butterfly (*Ano'sia plexip'pus*, Fig. 30). It is a tawny-colored species expanding about ten centimeters (four inches). The wings have black veins, and the margins are black with white spots. The colors are due to the presence of tiny scales, which cover the surface regularly and overlap like the shingles on a roof. Besides serving for the display of the colors, the scales also strengthen the wings. The scales are in origin modified hairs, like those which cover the rest of the body. The mouth-parts are formed for sucking the nectar of flowers, and consist mainly of a large tubular tongue, or *proboscis*, which is coiled up beneath the head. The proboscis is formed from the lengthening and union of the first maxillæ. The mandibles are so small as to be hardly visible. The anterior legs are so much reduced in size that they cannot be used for walking, and the butterfly is therefore practically four-legged.

The monarch passes the winter in the South, like our migratory birds, and with approaching warm weather the different individuals slowly work their way northward, the females laying eggs in different places in the course of the journey. The eggs are pale green and are deposited singly on the leaves of the different species of milkweed. In about four weeks the eggs hatch into caterpillars, which immediately proceed to devour the egg-shells. For the rest of their larval existence the caterpillars are voracious feeders on the leaves of the milkweed. They grow for two or three weeks, molting several times as they increase in size, till they are conspicuous objects, nearly five centimeters (two inches) long, prominently banded with yellow and black (Fig. 29). When through feeding, each larva spins a pad of silk on some convenient support, and, molting once more, appears in a mummy-like pupal condition (Fig. 29), attached by hooks at its extremity to the pad of silk spun by the larva. In the pupal stage the milkweed butterfly is bright green with golden spots. To this, and to some of the other naked pupæ of butterflies, the name *chrysalis* is sometimes given. The insect remains in the pupal stage for ten or twelve days, when the skin splits and the butterfly comes out with crumpled wings, which soon expand and harden.

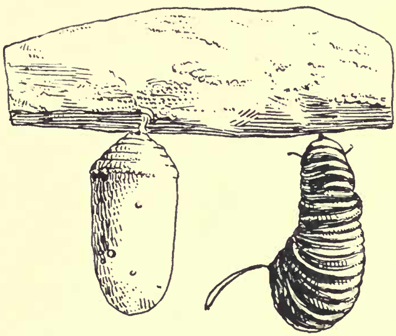


FIG. 29. Larva and Pupa of Monarch Butterfly. Natural size

(From Hunter's *Studies in Insect Life*)

The monarch butterfly possesses remarkable powers of flight. Mr. Scudder, in his *Guide to Butterflies*, mentions that it has been seen at sea five hundred miles from land, and that it has within thirty years spread over nearly all the islands of the Pacific, and even to Australia and Java. He says: "Undoubtedly carried in the first place by trading or other vessels to the Hawaiian Islands, and thence to Micronesia, it has unquestionably *flown* from island to island many hundreds of miles apart. It has also appeared at various times in different places on the seacoast of Europe; here also probably transported accidentally by vessels."

It is asserted that these butterflies, although so brilliantly colored and conspicuous, are not fed upon generally by birds and other animals which might use them for food, owing to their possessing a strong odor which renders them distasteful. If this is the case, the distinctive coloration may be an advantage rather than otherwise, making it easy for any animal to distinguish them from edible species. The brilliant colors are usually cited as an illustration of warning coloration.

The Viceroy Butterfly. Another butterfly of an entirely different genus (see p. 95) and without any offensive odor, — the viceroy (*Basilar'chia archip'pus*, Fig. 30), — closely resembles the monarch. The viceroy belongs to a group of butterflies whose general body-coloration is blue and white, but instead of the livery of its relatives it wears that of the monarch. It offers the best-known illustration in North America of what is called *protective mimicry*, a term applied to those cases in the animal kingdom in which a group of animals without disagreeable qualities resembles, to a greater or less extent, animals provided with special means of defense. Protective mimicry will be seen to differ from warning coloration in that the former is believed to protect an animal by marking it as a source of real danger or unpleasantness; the latter is believed to protect by suggesting characters which have no existence in fact. This explanation of the color of the viceroy has lately been called in question, and observations are wanting to show that the birds of the eastern United States feed generally upon butterflies. Many cases of protective mimicry are known among the butterflies of Africa and South America. By the use of the term it is not meant, of course, that there is anything conscious in the mimicry.

The White Mountain Butterfly. Another butterfly of the same group is the White Mountain butterfly (*Œne'is semid'ea*), interesting on account of its peculiar distribution. It is found only on the highest peaks of the White Mountains in New

FIG. 30. Monarch, Viceroy, and Type *Basilarchia*. Natural size

Upper figure, the monarch butterfly (*Anosia plexippus*); middle figure, the viceroy butterfly (*Basilarchia archippus*); lower figure, another species of the genus *Basilarchia*, to show the usual coloration of the genus

Hampshire and the Rocky Mountains in Colorado. As will be seen later, the geological period immediately preceding the present was an age of ice, in which the North American continent was covered by ice as far south as an irregular line drawn through New York, Pennsylvania, Missouri, South Dakota, and Oregon, and arctic conditions existed over the rest of the continent. At this time these butterflies were probably distributed over the country. As the ice slowly melted and the climate became warmer, they found only on the summits of these widely separated mountain ranges the conditions to which they had been accustomed, all those occupying the region between being driven to the northward or destroyed by the heat.

Swallow-Tail Butterflies. The magnificent insects called swallow-tail butterflies, widely distributed over the world, have received their common name on account of the prolongation of the posterior wings. They are especially interesting to the naturalist, not only for the variety and beauty of their colors and the elegance of their form, but also because they often exhibit, within the limits of a single species, great variation in color, size, and even in the shape of the wings. The variation in form, size, and color between individuals of the same species is spoken of as *dimorphism* (Gr. *di*, two; *morphe*, form), if the variations show two well-marked types; and as *polymorphism* (Gr. *poly*, many), if there are several different variations. In many species the males differ greatly from the females; this is called *sexual dimorphism*. Many examples are known of broods of the same butterfly appearing at two different seasons. These broods often differ widely in size and color markings. This is known as *seasonal dimorphism*. In some cases seasonal dimorphism and polymorphism seem to result from conditions of temperature. A swallow-tail butterfly (*Papil'io a'jax*), which is widely distributed in the eastern United States, has, in the latitude of West Virginia, three different forms, called the early spring, the late spring, and the summer form. Both of the spring forms appear from pupæ which have lived through the winter. From the eggs which the spring forms lay the summer form develops several successive broods the same year.

Skippers. The skippers (*Epargy'reus tit'yrus*, Fig. 31) are, like the butterflies, diurnal insects, and are found in fields and along woodsides, where they dart about in a most erratic manner. They are closely allied to the butterflies, but differ from them in several details of structure and habits. The butterflies (see Fig. 30) have club-shaped antennæ, while in the skippers the antennæ, though enlarged at the end, are generally recurved, forming a hook. The skippers have stouter bodies than the butterflies, and most of them hold the wings upright after the fashion of the butterflies; but some hold only the anterior wings in this position. The larvæ of those species found in the United States can easily be distinguished from other caterpillars by the very large head and strongly constricted neck (Fig. 31). They usually live in a folded leaf, or in a nest of leaves, and pass the pupal stage in a thin cocoon of silk spun by the caterpillars before changing. In this latter respect, too, the skippers differ from the butterflies, since the latter (as shown in Fig. 29) have a naked pupal stage.

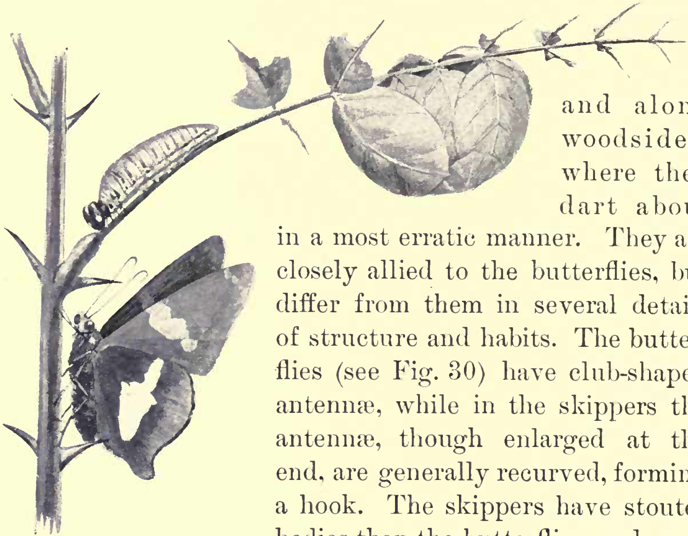


FIG. 31. Metamorphosis of Skipper. Natural size

Silkworm Moths. Allied to both butterflies and skippers is the great group of moths, — stout-bodied insects, the antennæ of which are usually feather-like or thread-like (Figs. 32, 33, 34). Moths have the habit of holding the wings horizontal when at rest. They are nocturnal or diurnal in their habits, though by far the larger number fly by night. Most of them spin some kind of a cocoon in which they pass the pupal stage.

We shall first consider the silkworm moths. Of these the best known, as it is economically the most important, is the Chinese silkworm moth (*Bom'byx mo'ri*). Cultivated in China from very early times, the Chinese jealously guarded the secrets of the manufacture of silk until, as the story goes, in the middle of the sixth century two monks brought the eggs to Constantinople by stealth, concealed in a hollow bamboo cane. The cultivation of the silkworm then spread rapidly to those parts of Europe suited to its culture. It was introduced into England in the fifteenth century, but the manufacture of silk was given no impetus till the arrival in 1585 of a body of Flemish weavers, who had fled from the Low Countries on account of the struggle with Spain. One hundred years later the revocation of the Edict of Nantes drove a large body of skilled workmen from France to England, Germany, and Switzerland, and the silk-manufacturing industry developed still more in these three countries. From 1609 to the present day various efforts have been made to introduce silk culture into the United States, the plan of bounties and rewards to stimulate its growth having been tried by the rulers in colonial days, and by several states since the war of 1861–65. These artificial means have so far not met with great success. In China the caterpillar thrives best on the leaves of the white mulberry, but it has been found to do well on the Osage orange, a tree widely distributed in the south and west of the United States.

The silk-glands extend through the body of the caterpillar and open into the mouth. Toward the time of pupation they increase in size and produce about four thousand yards of material, which, on being exposed to the air, hardens and becomes the silk of commerce. As there are two sets of these glands, each silk filament is really double. Within this cocoon of silk the larva casts its caterpillar skin and becomes a pupa. In silk-culture the cocoons are placed in an oven to kill the pupæ, and the silk is softened by being placed in warm water. Then, by means of a twig moved about among the cocoons, loose ends of several of them are caught, united into one thread, and wound on a reel, which is placed at a distance from the hot water so that the silk may dry. This is the raw silk of commerce.

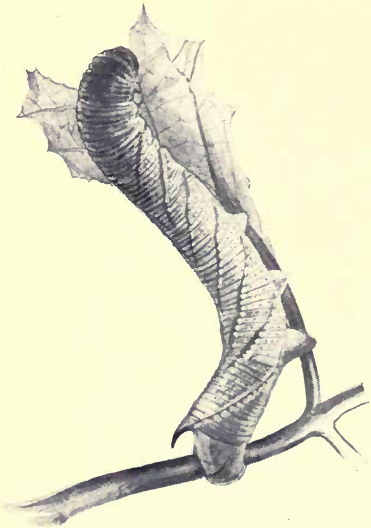
We have several large moths in the United States, expanding from ten to fifteen centimeters (four to six inches), whose larvæ spin silken cocoons, some of which have been utilized to a limited extent by man. They are magnificent insects, with broad wings beautifully colored, and with large feather-like antennæ. The larvæ feed on the leaves of forest and fruit trees, and are more or less armed with a variety of colored spines and tubercles. The caterpillars, like other larvæ which feed upon plant food, are remarkable for the amount of food which they consume and the great increase in size in early life. The caterpillar of the American silk-worm moth (*Te'lea polyphe'mus*), which weighs on hatching one twentieth of a grain, increases to ten times its weight within ten days, and to over four thousand times its weight in fifty days. By this time it has consumed over one hundred oak leaves, weighing almost three quarters of a pound, and drunk nearly one half an ounce of water. The larvæ of these moths spin conspicuous brown cocoons, which can easily be collected in the winter from the branches and leaves of trees to which they are attached. In the spring the imagoes escape from one end of the cocoons by cutting the silk with a pair of stout spines, one on each side of the thorax, at the base of the anterior wings.

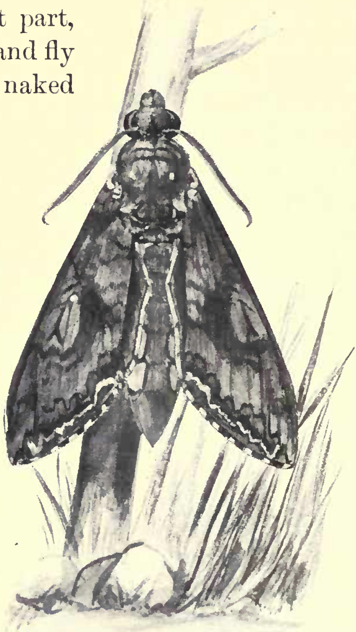
Underwings. A very striking group of moths is the underwings (*Catoc'ala*, Fig. 32), which have the anterior wings in sober tints of brown or gray, but the posterior wings black with broad markings of red or yellow. When at rest, as shown in the figure, the posterior wings are covered and the moth tends to be protectively colored; but when in flight the broad, contrasting colors are conspicuous. It is usual to account for the coloration of the anterior wings by the principle of protective resemblance. Some naturalists have thought that the bright colors of the posterior wings demand no other explanation than that they have resulted from a natural tendency to bright colors; while others have suggested that they serve to call attention to a non-vital part.

Fig. 32. Underwing at Rest. Reduced

Hawk-Moths. The hawk-moths or sphinx-moths (Fig. 33) are easily recognized by the stout conical body, long coiled proboscis, narrow pointed wings, and the slender antennæ.

They are dressed, for the most part, in quiet olive and brown tints, and fly by day. Their larvæ are large, naked





caterpillars, often with a curved horn near the posterior extremity. They have the habit of resting with the head and front of the body raised in the air. In this attitude they have been fancied to resemble the Egyptian sphinx. It has been thought by some zoölogists that this position is assumed as a terrifying attitude. The tobacco-worm is the larva of the

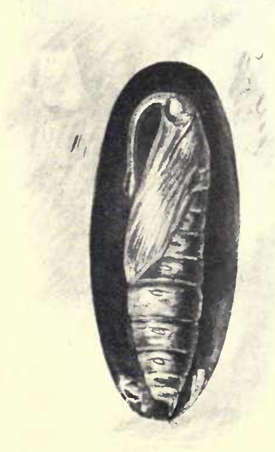


Fig. 33. Metamorphosis of Sphinx-Moth. Reduced

well-known species, *Phlegethon'tius sex'ta* (Fig. 33), found on tomato, potato, and tobacco plants. The larva, though often credited with poisoning people by stinging them with the long curved caudal horn, is in reality entirely harmless. The pupa is remarkable for the long coiled proboscis-case.

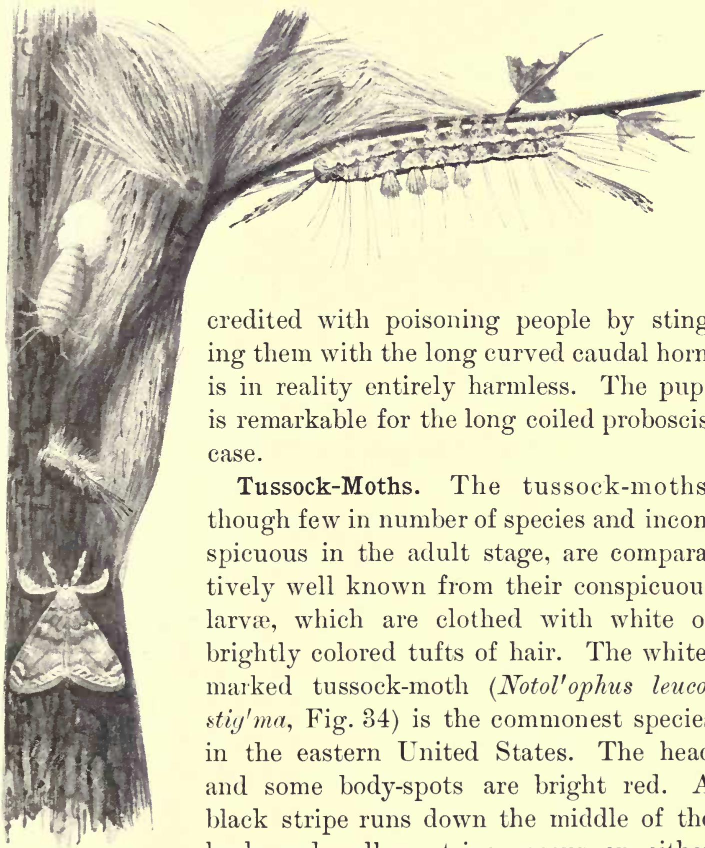


Fig. 34. Metamorphosis of Tussock-Moth. Natural size

Tussock-Moths. The tussock-moths, though few in number of species and inconspicuous in the adult stage, are comparatively well known from their conspicuous larvæ, which are clothed with white or brightly colored tufts of hair. The white-marked tussock-moth (*Notol'ophus leucostig'ma*, Fig. 34) is the commonest species in the eastern United States. The head and some body-spots are bright red. A black stripe runs down the middle of the back and yellow stripes occur on either side. Long brushes of black hairs are borne anteriorly and posteriorly, while four dense clusters of white hairs stand up prominently from just behind the head. The females are wingless and look more like white grubs than moths. When they emerge from the cocoons the eggs are laid near by, often on the cocoons. Fig. 34 shows the female in the act of laying eggs in such a situation.

Observations on the food of birds of the eastern United States seem to show that the spines, tubercles, and hairs, with which many caterpillars are covered (compare Fig. 35, the larva of the regal moth, *Cithero'nia rega'lis*), form very efficient means of protection, — at least from birds, — since, with the exception of the cuckoo, no bird is known to make a practice of feeding on hairy caterpillars. Professor Poulton of Oxford, England, experimented with a species of tussock-moth from England to determine the part the tufts of hair play in the life-economy of the caterpillar. He says: "A caterpillar of the common vaporer moth (*Oryg'ia anti'qua*) was introduced into a lizard's cage, and when attacked instantly assumed the defensive attitude, with the head tucked in and the tussocks separated and rendered as prominent as possible. An unwary lizard seized the apparently convenient projection; most of the tussock came out in its mouth, and the caterpillar was not troubled further. The lizard spent a long and evidently most uncomfortable time in trying to get rid of its mouthful of hairs."

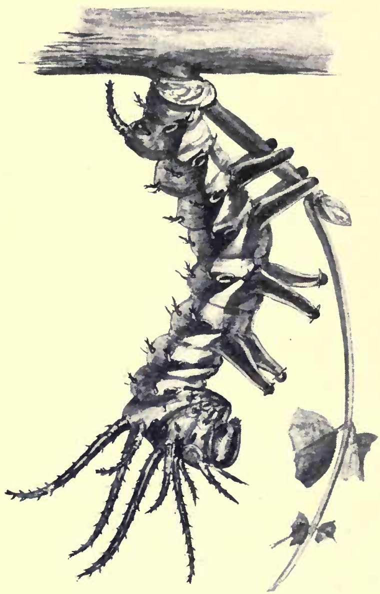


FIG. 35. Larva of Regal Moth. Reduced

Measuring-Worms. The measuring-worms (Fig. 36) are the larvæ of a group of medium-sized moths, which afford many illustrations of protective resemblance. When some of these larvæ are at rest, standing out stiff from a twig, it is difficult to believe them to be caterpillars. Most of them have three pairs of legs less than other caterpillars, so that a looping gait is the result, whence the name, "measuring-worms." They have the habit, when disturbed, of dropping to the ground on a silken thread, which they spin as they fall.

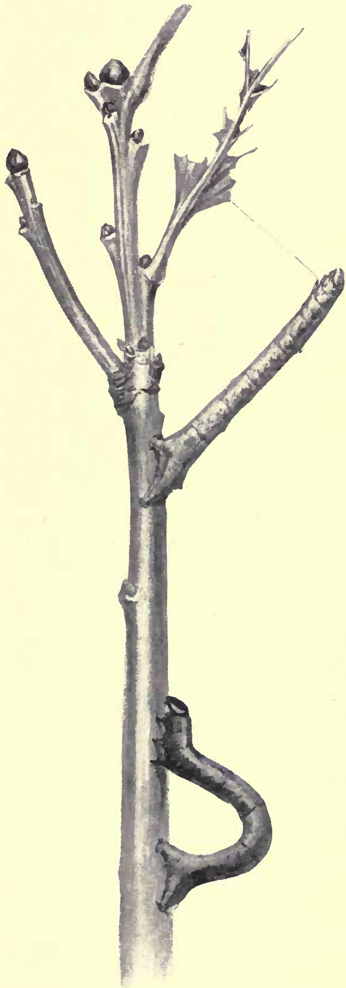


Fig. 36. Measuring-Worms. Natural size

Definition of Lepidoptera (Gr. *lepis* (*lepidos*), scale; *pteron*, wing). The butterflies, skippers, and moths, collectively, are spoken of as *Lepidop'tera.* The Lepidoptera have four large wings covered with scales, sucking mouth-parts, and undergo a "complete" metamorphosis. The larvæ, called caterpillars, with few exceptions, feed upon the leaves of plants. They pass a greater length of time in the pupal stage than the other insects we have thus far considered.

CHAPTER VII

THE FLIES: DIPTERA

. . . like small gnats and flies as thick as mist
On evening marshes. — SHELLEY.

House-Flies and Flesh-Flies. The common house-fly (*Mus'ca domes'tica*, Fig. 37) is a cosmopolitan insect. The eyes are very large, occupying the whole side of the head; the antennæ are short and composed of only three joints, the third bearing a bristle. The mouth-parts are formed for sucking and lapping. They consist of a short tongue-like proboscis, with large oval flaps, or lobes, on each side. These flaps are extensile, and are roughened like a file on the inner surface, thus permitting of their use as a scraper, by means of which the insect can lap up sweets or other food. The proboscis is made up of the united maxillæ. The thorax is globular and bears but one pair of wings, though the rudiments of others, called "balancers," can be seen in the form of two little round objects, borne on slender stalks. These

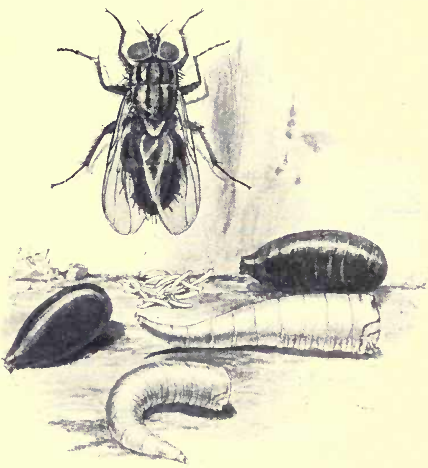


FIG. 37. Metamorphosis of House-Fly. Enlarged

balancers also act as organs of hearing. Two broad scales are found on the sides of the thorax, just behind the wings. The legs are fitted for running, and the pulvilli are large and bear tubular hairs, which secrete a sticky fluid by means of which the fly can walk on smooth surfaces, even when upside down.

The eggs, over one hundred in number, are laid usually in horse-manure, and hatch within a day into smooth white, almost transparent, conical, footless larvæ, called maggots. They have rudimentary mouth-parts, consisting only of a few small hooks. The larvæ feed for about a week, growing rapidly and molting twice within that time, and then pass into an inactive pupal stage within the larval skin. In a week more the perfect insect appears by making a circular hole in one end of the pupal case by means of a large bladder-like bulb, which swells out on the forehead and is later withdrawn into the head. The life-history is thus completed within about two weeks, and as the imagoes soon lay eggs, there may be several generations in the course of the summer. On the approach of cold weather most of them die, though some hibernate in sheltered places.

The house-fly has always been considered a nuisance about the house; but lately a more serious charge has been laid at its door, — that of transporting on the pulvilli and proboscis the germs of typhoid fever. With the knowledge of its favorite breeding-place it should be possible, by insisting on cleanliness in stables, by the daily collection of manure and its disposal in a closed place, or by treatment with chloride of lime, to greatly mitigate, if not entirely destroy, this menace to health.

Equally well known are the blow-fly (*Calliph'ora vomito'ria*) and the bluebottle (*Lucil'ia cae'sar*), which deposit their eggs on fresh and decaying meat. These flies hatch within a day, and the larvæ greedily devour the decaying material, not hesitating, when that task is finished, to devour each other.

The famous tsetse fly of South Africa (*Glossi'na mor'sitans*), whose bite is almost certainly fatal to the ox, horse, and dog, belongs to the same family as the species just mentioned. It has been found almost impossible to build up certain sections of South Africa, owing to the prevalence of this insect. An English army surgeon has lately discovered that by its bite it introduces disease germs from sick animals into the blood of healthy ones.

Bot-Flies. The bot-flies are parasites in the larval stage; that is, they live in the bodies of other animals. There are

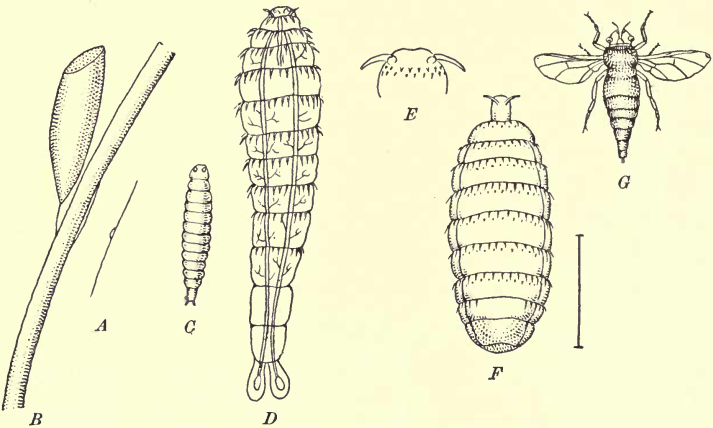


Fig. 38. Metamorphosis of Horse Bot-Fly. (After Osborn, *Bulletin No. 5*, n.s., United States Department of Agriculture, Division of Entomology)

A, egg on hair of horse (natural size); *B*, egg on hair of horse (enlarged); *C*, young larva (enlarged); *D*, young larva (much enlarged); *E*, spines; *F*, full-grown larva (twice natural size); *G*, female (natural size)

nearly one hundred species known, infesting various animals, living either under the skin, in the nostrils, or in the stomach. The bot-fly of the horse (*Gastroph'ilus e'qui*, Fig. 38) attaches its eggs singly by means of a sticky substance to the hairs of the legs, where the larva is pretty sure to be swallowed when the animal licks or bites its legs to remove the irritation.

The larva then attaches itself to the lining of the stomach by means of hooks, which encircle the mouth, and for nearly a year feeds on the substance of the stomach-wall. The pupal stage is passed in the earth, which is reached through the alimentary canal. A few of these parasites do no particular harm, but a large number may cause death.

The sheep bot-fly (*Œs'trus o'vis*) in a similar manner attacks the nostrils of sheep. The appearance of one of these flies in a flock of sheep is sufficient to throw them into a state of panic; they run about with their noses between their legs, or try to bury them in dust, to escape their tormentors. The female bot-fly does not lay her eggs as do most other insects, but retains them within her body till they hatch, and then deposits the living young, — that is to say, she is *viviparous*.

Hover-Flies. Often a collector captures an insect flying about flowers, which has the characteristic manner and yellow and black colors of a wasp, but which has only two wings. It is one of the hover-flies, many of which afford illustrations of protective mimicry. Some species of *Eris'talis* (Fig. 45) mimic the male honey-bee, and are therefore named drone-flies; others belonging to *Volucel'la* (Fig. 45) mimic bumble-bees. The larvæ of some feed upon aphids, and are therefore beneficial to the farmer; others inhabit pools of stagnant water or decaying wood. Several are called rat-tailed larvæ, from the presence of a long tube projecting from the posterior end of the body, which enables the larva to get air when submerged. The larva of the drone-fly is of this type. Other species are found in ants' nests.

Mosquitoes. The mosquitoes are a group widely distributed over the tropical and temperate regions of both hemispheres. In nearly all the species observed the mouth-parts of the females only are fitted for piercing the skin of animals. The males, if they feed at all, probably suck the fluids of plants; in fact, both sexes in the past history of the race were probably, and are still, to some extent, plant-feeders.

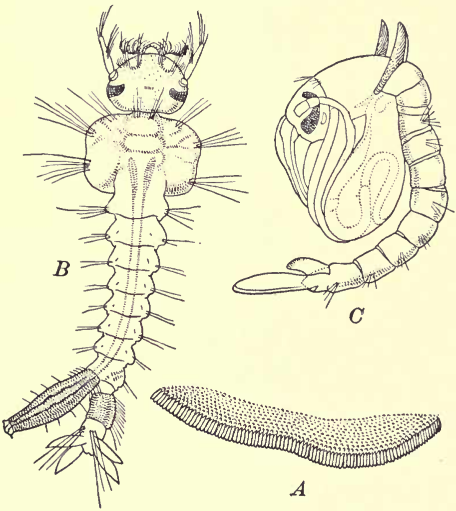


Fig. 39. Development of Mosquito. Enlarged. (After Howard, *Bulletin No. 25*, n.s., United States Department of Agriculture, Division of Entomology)

A, egg-mass; *B*, larva; *C*, pupa

The common mosquito of the Mississippi valley and the East is *Cu'lex pun'gens* (Fig. 39). The female lays her eggs in irregular masses, containing over two hundred eggs, on the surface of the water early in the morning. Within a day they hatch, and the larvæ are the familiar, active creatures known as "wrigglers." The next to the last somite bears a long respiratory tube through which the larva breathes air when at the surface; the last somite is provided with four flaps (tracheal gills) which act as organs of respiration when the larva is beneath the surface. In addition to these methods of obtaining air, the skin is capable of absorbing oxygen, and a network of tracheæ lines the posterior part of the alimentary canal, so that oxygen may be obtained from the water taken in at the anal opening. The larvæ feed on small particles of decaying matter in the water, thus being useful as scavengers. After several molts and a life of about a week, if the weather is warm they then pass into the pupal stage, breathing by means of two air-tubes arising from the thorax. In about two days the pupal skin splits down the back and the imago works itself out of its old skin, dries its wings, and flies away. Cold weather retards these changes considerably.

Great interest attaches to the mosquitoes by reason of the recent indictment that some species transmit malaria and yellow fever. Malaria is carried by mosquitoes belonging to the genus *Anoph'eles*, the females of which may be distinguished from the females of Culex by the greater length of the palpi. The males of both genera can be distinguished from the females by their more feathery antennæ. Anopheles shows a tendency, especially on horizontal surfaces, to alight with the hind end of the body raised at a considerable angle to the surface; Culex holds the body parallel to the surface. In Anopheles the body and beak are in the same plane no matter what the position is; Culex is humpbacked, with the beak pointing downward. These various distinctions are well shown in Fig. 40. The disease known as malaria is caused by the presence in the blood of a parasitic organism, one of the lowest forms of animal life, known as *Plasmo'dium mala'riæ.* Its rapid development at certain stages produces the well-known fever connected with the disease. The life-history of the organism is described in Chapter XXI. The most extensive experiments concerning the connection between the Anopheles mosquito and malaria have been carried on by the British Colonial Office and the British School of Tropical Medicine. Two physicians, under the auspices of these institutions, established themselves in the fever-infected Roman Campagna. They took no special precaution against the disease, drinking the water of the district and in other ways conforming to the

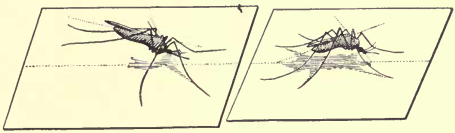


Fig. 40. Resting Positions of Anopheles and Culex. Slightly enlarged. (After Grassi)

customs of the people, save only that they did not allow themselves to be bitten by the Anopheles mosquito, which swarms in that region at the close of day. They slept during the night in a mosquito-proof house, and did not contract malaria. Persons, on the other hand, with no traces of malaria, have allowed themselves to be bitten, and thus contracted the disease. It seems, from these and other experiments, that the malarial parasite is injected into the blood with the saliva of the insect, and it further appears that, in order to complete the life-history of the parasite, it must enter the salivary gland of the mosquito. Quinine is a specific, because it kills the organism at a certain stage in its life-history. United States army surgeons in Cuba have been instrumental in clearing up the life-history of the yellow-fever germ, which seems to be transmitted by mosquitoes of the genus *Stegom'yia.*

Many localities can be practically rid of these pests by the drainage of the swamps or ponds in which they breed; by the use of kerosene on the surface of such waters; or by the introduction of fish that feed on the larvæ. Among the fishes recommended are sunfish and sticklebacks. It must be remembered that the insect will breed successfully in any transient pool of water, or in any receptacle where water is left standing long enough for the changes just described to take place. Experiments are being conducted in the Middle West with a fungous disease similar to that which destroys large numbers of flies in the autumn.

Definition of Diptera (Gr. *dipteros*, two-winged). The insects collectively called flies agree in the possession of two wings, the place of the posterior pair being taken by the balancers, which may therefore be considered reduced wings. The flies belong to the order *Dip'tera.* The Diptera have the mouth-parts fitted for sucking or piercing. They undergo a "complete" metamorphosis. The larvæ are commonly known as maggots.

CHAPTER VIII

THE ANTS, BEES, AND WASPS: HYMENOPTERA

For so work the honey-bees,
Creatures that by a rule in nature teach
The art of order to a peopled kingdom.

SHAKESPEARE, *King Henry V.*

Social Wasps. The common brown wasps (*Polis'tes*, Fig. 41) are interesting on account of their communal life in nests of paper made from wood-pulp. The mouth-parts are fitted both for biting hard substances and also for lapping the fluids of plants. The mandibles are much the same as in such biting insects as the locusts; the first maxillæ are elongate, sharp-pointed, lance-like organs, and the second maxillæ are modified into a flexible, tongue-like structure covered with hairs, to which sweets adhere. There are four membranous, transparent wings, with few veins. The female is provided with a formidable sting, — an important means of defense, — which is in origin a modified ovipositor.

Early in the spring a female Polistes, which has wintered in a crevice, begins the construction of a nest in some suitable place, either on the under side of a roof, especially in deserted houses or barns, or on the ground beneath a stone. If there are fences or barns in the region, she will very likely obtain a supply of wood from them; if not, from stumps and dead trees. After being chewed by her and moistened by a secretion from her mouth, this material is fashioned by the feet and mandibles into circular cells, which become hexagonal as their number is added to and the pressure increases. The whole is waterproofed by a glutinous secretion, which is said to be increased in amount in those cells which are most exposed to the weather. As soon as one cell is finished the female lays an egg in it, and to her duty of enlarging and strengthening the nest she soon has to add the care of the footless, worm-like larvæ, which hatch in a few days. These are fed with both plant and animal food, the former consisting of nectar which has been swallowed and later regurgitated (i.e. thrown back after being swallowed); the latter, of caterpillar meat chopped fine by the mandibles and worked into a jelly-like mass. In about three weeks' time the first-born larvæ spin a silken lining and covering to the cell and pass into an inactive pupal stage. Three weeks later the first imagoes appear, after having cut a circular opening in the end of the cell.

These first imagoes differ somewhat from their mother, and are really imperfectly developed females, called neuters, or workers. They have the power, under certain conditions, of laying eggs, but their eggs never produce true females. Generally the workers attend strictly to the business of caring for the young and repairing and enlarging the nest. They assume care of the young at about the third day.

This habit may be due primarily to imitation of the female, whom the worker sees repeating the act while it is waiting for the hardening of its tissues, or to the early development of an instinctive tendency to perform the act (see p. 85). Experiments performed by Dr. Enteman of the University of Chicago, in which newly developed workers were given bits of food at intervals before they had had any association with others of their kind, seem to show that it is an instinct which appears very early, but not at the same time with all workers. When it does appear, owing to the presence of food furnished by the female, the steps are, according to Dr. Enteman, "first the crushing and molding, then a slow walking around the nest with frequent pauses, and, if larvæ are present, the pinching off of the food bit by bit until all has been disposed of. If no larvæ are present, — if, for instance, the young worker is living in an inverted tumbler and has never seen a larva, — the various stages of the process are the same." The instinct does not appear in perfection at first, for the same author notices that it takes a young worker about three times as long to feed the larvæ as the female requires, and that a great deal of time is lost by the new worker "in poking its head into the wrong cells and running unnecessarily about over the face of the nest."

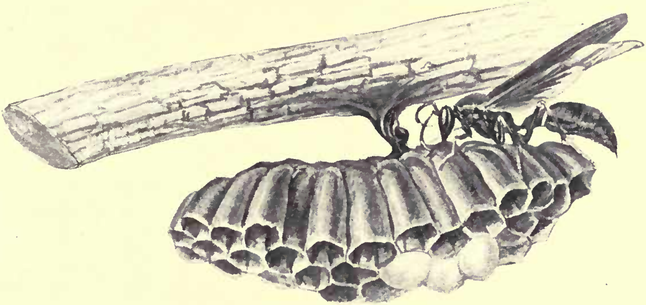


FIG. 41. Paper-Making Wasp and Nest. Natural size

The workers surely do not appreciate the character of their task, for the observer just quoted has seen a young worker gnaw a piece out of the body of a dead larva and offer it as food to the mouth of the same larva; and, she continues, "I once observed a neuter attack a live larva, and after she had cut out and crushed a fair-sized piece of its body, come back eight times in the course of her examination of the cells of the nest, to this larva, which naturally had died in the operation, and offer it this part of its own body, with the evident expectation that it would be seized and eaten. The eighth time she dropped the piece on the face of the dead larva and went away with an air of 'duty well done' which was comical to behold."

From the time the workers take up the tasks of the nest the female is left free to devote all her energies to laying eggs, and the nest is rapidly made larger by the workers. Toward September males and females appear from the cells, which up to this time have produced only workers. The males die soon after mating. On the approach of cold weather, the workers also die, and only females remain to hibernate and begin a new nest the next spring.

Another type of nest, in which the horizontal layers are inclosed in a thin envelope, is made by the somewhat larger and stouter-bodied wasps (*Ves'pa*, Fig. 45) commonly known as "hornets." These wasps are generally conspicuously marked with yellow, and their nests may be a foot and a half in diameter.

The social wasps are the original paper-makers of the world. The first suggestion as to the manufacture of paper by man may have come from watching the work of these insects, though the necessary steps may well have been taken without such suggestion, as the use of the leaves of palms and the bark of several trees is still common in China and India. It is interesting to note that though the wasps were the original inventors of paper, they have, in some cases, learned to take advantage of man's present greater facilities for its manufacture, thus saving themselves the trouble. In one case in Missouri the wasps found the damp paper of bags, which had been tied over grape-clusters in a vineyard to keep out injurious insects, so much to their liking that they used it freely instead of their own wood-pulp paper.

Solitary Wasps. Those wasps which are solitary in habit make nests in various situations and of different materials, and store them with food, generally insects and spiders, which they often sting so as to paralyze but not to kill them. Each species has its own method of providing food, and each keeps pretty closely to the same material for nest-building. Thus the common mud-dauber (*Pelopæ'us*, Fig. 42), seen flying about on sunny days over the muddy edges of puddles and pools, builds its nests of clay and provisions them with spiders. Each cell is filled with paralyzed spiders; on top

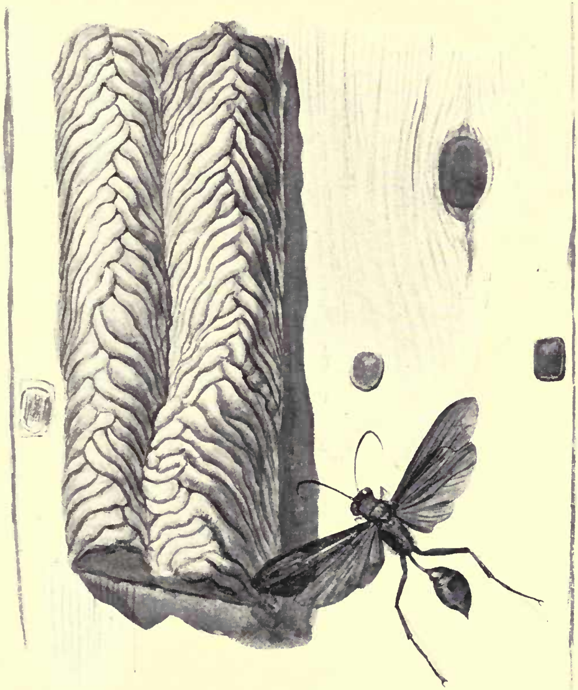


Fig. 42. Mud-Dauber and Nest. Natural size

one egg is laid and the cell is sealed. When the larva hatches it finds the requisite amount of food to carry it to the pupal stage. These wasps are distinguished by the long pedicel, or stalk, joining the thorax to the abdomen.

The digger-wasps of the West, which belong to the genus *Ammoph'ila* (Fig. 43), make holes a little over a centimeter (about half an inch) in diameter and two or three centimeters deep, in the hard, sun-baked earth, often choosing a place beneath the protection of the leaf of some plant. These holes they provision with caterpillars, which they sting in several

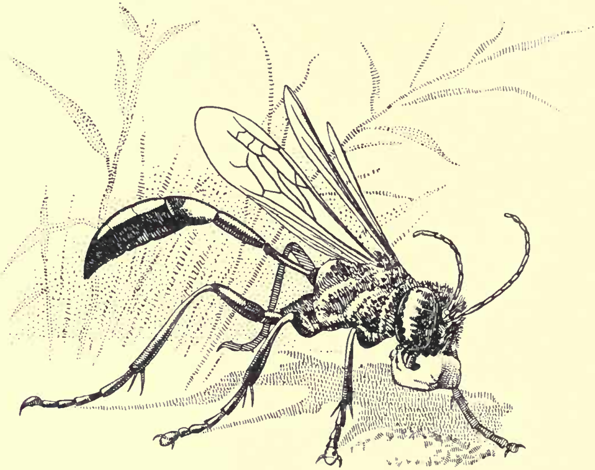


FIG. 43. Digger-Wasp using Pebble. Enlarged
(From Peckham's *The Solitary Wasps*)

places till they are paralyzed. In the process of provisioning the nest some species close the opening with a pellet of earth or with small stones, which they remove when they return with a new caterpillar. Dr. and Mrs. Peckham, who have studied these insects very carefully, say that this is, however, not an invariable habit, some individuals leaving the nest open while searching for more caterpillars. These authors have this to say of the habits of one of these insects.

"Just here must be told the story of one little wasp whose individuality stands out in our minds more distinctly than that of any of the others. We remember her as the most fastidious and perfect little worker of the whole season, so nice was she in her adaptation of means to ends, so busy and contented in her labor of love, and so pretty in her pride over her completed work. In filling up her nest she put her head down into it and bit away the loose earth from the sides, letting it fall to the bottom of the burrow, and then, after a quantity had accumulated, jammed it down with her head. Earth was then brought from the outside and pressed in, and then more was bitten from the sides. When, at last, the filling was level with the ground, she brought a quantity of fine grains of dirt to the spot, and, picking up a small pebble in her mandibles, used it as a hammer in pounding them down with rapid strokes, thus making this spot as hard and firm as the surrounding surface. Before we could recover from our astonishment at this performance she dropped her stone and was bringing more earth. We then threw ourselves down on the ground, that not a motion might be lost, and in a moment we saw her pick up the pebble and again pound the earth into place with it, hammering now here and now there, until all was level. Once more the whole process was repeated, and then the little creature, all unconscious of the commotion that she had aroused in our minds, unconscious, indeed, of our very existence, and intent only on doing her work and doing it well, gave one final comprehensive glance around and flew away."

FIG. 44. Mason-Wasp and Nest. Natural size

A common North American species of solitary wasp (*Eume'nes frater'nus*, Fig. 44) builds a pretty little jug-shaped nest of clay or mud, which it attaches to vegetation and provisions with caterpillars. The young, when full-grown, escape through a hole which they cut in the side of the nest, as shown in the figure.

The Honey-Bee. The life-history of the honey-bee (*A'pis mellif'ica*, Fig. 45) has been quite well understood for a long time. This insect offers a most interesting illustration of a society all the members of which act together for the good of the community. In their community specialization of work has been developed to a remarkable extent. The honey-bee, originally a native of the eastern hemisphere, possibly from the region along the eastern shore of the Mediterranean Sea, has been domesticated from very early times for the sake of its two important products, honey and wax. Escaped swarms in this country have become the wild honey-bees, which nest in hollow trees. In early summer a bee community in good condition may contain from twenty-five to thirty-five thousand workers, several hundred males, called drones, but only one female, called the queen bee. The queen bee may be distinguished from the workers and drones by her larger size; the drones are stouter than the workers.

Upon the workers devolves most of the labor in connection with the life of the community. They secrete the wax and fashion it into the cells of which the home is composed. They bring water to the hives. They collect nectar from flowers and later regurgitate it and ripen it into honey; they bring pollen to mix with nectar to make "bee-bread," and gather propolis, a gummy substance from the bud-scales of certain trees, especially the poplar, for filling crevices and covering foreign objects which are too big to remove from the nest. When the young are hatched the workers act as nurses and housekeepers for the community, feeding the young and keeping the hive free from all substance which might decay. In warm weather some of them may be seen at the entrance and along the passageway, keeping the air in motion with their wings, thus setting up a current which provides air and helps ripen the honey by evaporating the water in it. Finally, as every one knows, they are the defenders of the hive, and by their great numbers and formidable stings they constitute a body-guard of no mean pretensions.

The name "queen bee" is misleading, if it suggests any control or management of the affairs of the hive. She is carefully guarded by the workers, but that is on account of her importance to them as the only fertile female in the community, though they can, as we shall see, produce other queens from eggs which were destined for workers, if necessity arises. As far as having any power to rule is concerned, she is, in reality, ruled by the workers. It is her function to lay the eggs from which all the other members develop. Those eggs destined to become workers are laid in cells of ordinary size; those which are to become males are placed in slightly larger cells; while those which are to become queens, though differing in no way at first from those which produce workers, are placed in special "royal" cells, much larger and of an irregular shape. They are, of course, few in number compared with the others.

When the eggs hatch, all the larvæ are fed for several days on a jelly-like substance consisting of regurgitated food mixed with a secretion from glands in the heads of the workers and poured out from their mouths. After this the workers and males receive "bee-bread," a mixture of pollen and honey, while the young queens are continued on their diet of elaborated material, "royal jelly," furnished by the workers. When for any reason a hive loses its queen, the workers proceed to break down the walls between three adjacent cells containing worker larvæ, kill two of the occupants, and bring the third to maturity as a queen by the use of royal jelly. The first eggs laid in the spring produce workers; the males are produced from unfertilized eggs laid by the queen.

When the larva is full grown no more food is supplied to it and the cell is sealed with a waxen cover. Within this prison the larva spins a cocoon and changes to a pupa. Within three weeks from the laying of the egg the worker bee cuts a hole in the covering of its cell and emerges. A queen is produced in somewhat less time; a drone requires slightly longer.

In late spring or early summer, as the colony has increased in size, the time approaches for one of the new queens to appear from the pupal stage. A peculiar noise may be heard, made probably by the wings of the imprisoned queen. Part of the ordinary work of the hive is neglected, and the old queen rushes forth with a large number of the community, generally alighting in a palpitating mass on some near-by tree or other support. This is the "swarming" of the bees. If provided with a new hive, they will generally settle down quietly in their new home. Bees are particular as to the state of the weather at the time of swarming, appearing only when the sky is clear. The workers carry a store of honey in their crops, as if prepared for a long trip, which in a state of nature may often have occurred before the bees could find a hollow tree or crevice among rocks suitable for a home. The swarming serves the purpose of lessening the chances of a total extinction of the species, by increasing the number of communities.

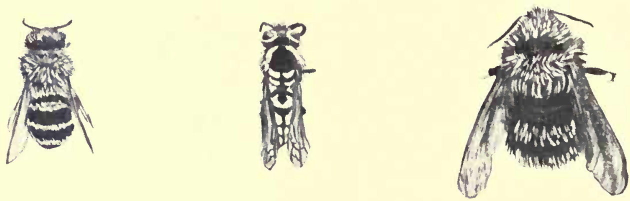
Meanwhile the new queen appears in the old hive, and after a flight in the air with the drones, during which fertilization occurs, she settles down to her duty of egg-laying. This flight and the swarming are the only occasions upon which the queen leaves the hive. The number of swarms thus given off varies with the size of the original community, and seems to depend somewhat on climatic conditions. It is not uncommon to have three swarms in a season. When the community is to send out no more swarms, the queen is permitted to sting the other young queens to death. If by any chance two queens meet, a conflict begins at once, and the usual result is the death of one of them. This is often spoken of as due to the jealousy of the queens, but it may have a meaning in connection with the necessity the community is under of sending out swarms to maintain a separate existence. The sting of the queen is used only in these battles and in slaying the young queens. At the end of the swarming season the workers set upon the drones and kill them, casting their dead bodies out of the hive. The queens live for several years, depositing two or three thousand eggs a day during a part of the season. The workers live, as a rule, less than two months.

The wax of which the cells of the comb are composed is secreted in the form of thin plates in "wax-pockets" beneath some of the abdominal somites. While preparing this, full-fed workers hang motionless to the cells in the upper part of the hive, and in about twenty-four hours the wax appears. This is removed by other workers and is used in construction. Honey is made for food for the young and for winter consumption of the colony. The pollen of flowers is brought to the hive in "pollen-baskets," clear spaces surrounded by hairs on the outer side of the hind tibiæ. The basal joints of the hind tarsi are much enlarged, and are used as brushes to gather the pollen.

Bumblebees and Guest-Bees. The bumblebees (*Bom'bus*, Fig. 45) are social bees, having homes in fields, in deserted mouse-nests and similar places. The nest is begun early in the spring by a female which has wintered, and, as with the social wasps, the burdens of the home are turned over to the young workers when they emerge. Late in the season other females and males appear, but there is no swarming as with the honey-bee. On the approach of cold weather the workers and males die. The honey made is strong-smelling, but much sought after by boys in the country, perhaps as much for the danger connected with its capture as for the sake of the honey itself. Boys in the West rob the bees by placing a gallon jug partially filled with water in the vicinity of the nest and thoroughly arousing the members of the community. The boys make good their escape to a safe distance, and the bees, perceiving the jug, fly to its open mouth, which echoes the buzzing of their wings. Angered by the sound, some bees fly

Mimicked Forms, — Insects with means of defense

The honey-bee (*Apis mellifica*) | A wasp (*Vespa occidentalis*) | A bumblebee (*Bombus Howardii*)



Mimicking Forms, — Insects without means of defense

A fly (*Eristalis latifrons*) | A beetle (*Clytus marginicollis*) | A fly (*Volucella evecta*)

Fig. 45. Mimicked and Mimicking Insects. Natural size.
From photographs
(From Hunter's *Studies in Insect Life*)

into the mouth of the jug, thus adding to the noise and attracting others. It is said that with two disturbances of the nest the worker bees can all be captured.

There are several bees called guest-bees (*Psith'yrus*), which live in the nest of the bumblebees, apparently on good terms with them, though they do not, so far as known, perform any useful function. Their eggs are laid with the eggs of the bumblebees, and the larvæ feed on the food which the bumblebees provide for their own young. Some of the guest-bees resemble their hosts quite closely; others are different in appearance, so that it cannot be said in all cases that the bumblebees are deceived by the resemblance. One effect of



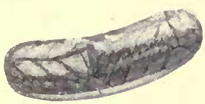


FIG. 46. Leaf-Cutter Bee and Nest. Natural size

the dependence of the guest-bees on their hosts is seen in the absence from the hind legs of the former of the pollen-collecting and pollen-carrying organs, which have probably been lost through disuse. It has been observed that the bumblebees sometimes resent the introduction of one of the guest-bees into their nest, though they may later become accustomed to it and make no further trouble.

Solitary Bees. There are solitary bees, just as there are solitary wasps. Their habits are very diverse; some make nests of mud or dig tunnels in the ground; some are carpenters, boring into wood; and others are leaf-cutters, taking circular pieces out of leaves, which they use to line their nests. Fig. 46 represents the work of one species, the leaf-cutter bee (*Megachi'le acu'ta*), which makes long tunnels in wood or in the ground. The eggs are laid singly on a paste of nectar and pollen, which is placed carefully in a leaf-lined cell and covered with a circular lid. Several such cells are generally to be found in one nest.

Ants. Ants have long been considered models of industry. In many respects some of the features of their life-history are the most remarkable of anything in the insect-world. So specialized have the members of the community become in some cases that there are not only males and females, but large and small workers (workers major and minor), and soldiers for the defense of the colony. Ants build nests in the ground, piling up the material taken out for their burrows in the characteristic ant-hills; or they make tunnels in wood. Some inhabit the interior of thorns or the hollow stems of grasses; others live on certain trees, from which they obtain all their food, forming a kind of body-guard by defending the tree from the attacks of various enemies. The food of ants is both animal and vegetable, the former consisting of other insects, the latter of plant fluids. They are also extremely fond of the sweet substance called "honeydew," furnished by the aphids and some few other insects.

The eggs are, of course, extremely minute, and hatch into footless larvæ, which resemble those of the bees and wasps. The workers take great care of the young, feeding them and moving them about in conformity with changes in temperature and amount of moisture. Among ants generally, the workers feed not only the young but even give up food to each other, when this is demanded by a stroke of the antennæ. The pupal stage is generally passed in silken cocoons. These are the so-called "ant-eggs," which are the objects of much solicitude when a nest is exposed. The imagoes are unable to escape from the pupal case without the help of the workers. The males and females are at first winged, and take flight in great numbers into the air on some warm day in spring. At this time fertilization occurs. On their return the males soon die, and the females, stripping off their wings, become the mothers of colonies. The females can be distinguished from the workers by their larger size and the presence of well-developed ocelli.

Many other insects, especially beetles, live habitually in the nests of ants, and, in some cases at least, seem to perform some useful function, — acting as scavengers, for instance. These cases, like that of the bumblebees and guest-bees, may be cited as illustrations of *commensalism* (Lat. *com* (= *cum*), together; *mensa*, table), an association of one species of animal with another for support or advantage, but not as a parasite.

An illustration of coöperation between two different species of animals is shown in certain ants and aphids. The corn-louse ant (*La'sius*) collects the eggs and young of a species of aphid (*A'phis mai'dis*), which attacks the roots of corn in the Middle States, and guards them throughout the winter in subterranean burrows, so as to provide a constant supply of "honey-dew." Some ants build a shelter of wood-pulp or mud over colonies of aphids, which are crowded on a branch, from which they derive their nourishment. These aphids are often spoken of as the cows of the ants. In these cases the relation between the ants and aphids is clearly of a more intimate character than the association of the bumblebees and guest-bees; and the advantages are mutual, for while the ants secure a constant supply of food, the aphids receive care and a certain amount of protection against their enemies. This association is spoken of as *symbiosis* (Gr. *syn*, together; *bios*, life).

An ant found in eastern Asia lives in shelters which it forms on the leaves of trees by fastening the edges of the leaves together. The imagoes have no sticky secretion for this work, but the larvæ have glands which furnish such a secretion for the purpose of spinning their cocoons. The imagoes seize the larvæ in their jaws, rubbing them backward and forward over the edges of the leaves, when the sticky

Fig. 47. Tunnels of a Mexican Blind Ant

secretion is poured out and the edges of the leaves are drawn together and kept there.

Fig. 47 shows the tunnels of a species of blind ant from Mexico, on the trunk of a "wild fig." The tunnels serve as a safe means of communication between the nest underground and the leaves of the tree.

The honey-ant of Texas (*Myrmecocys'tus mel'liger*) has one set of workers peculiarly modified to act as storage vessels for sweets. The abdomens of these are distended with a store of grape-sugar, till they are as large as a currant. These workers cling to the roof of the nest, and in times of famine can be drawn upon for food by the other workers.

The agricultural ant (*Myrmi'ca molefac'iens*), of the same region, clears large spaces, often several feet in diameter, cutting down all vegetation growing thereon, and rears a grain-bearing grass, storing its seeds in subterranean chambers. Several kinds of ants have the habit of attacking other kinds and carrying off their pupæ. In one (*Formi'ca sanguin'ea*), a small reddish species, the habit has become firmly fixed, and periodical raids are made upon a larger black species, which are afterwards raised in the nests of their captors. One ant of a slave-making tendency, found in Europe (*Polyer'gus rufes'cens*), has carried the habit so far that it has lost the power of feeding and taking care of itself, depending entirely on the exertions of its servants. The wars of ants have been known for a long time, and many accounts are extant of the fierceness of the struggle between opposing armies.

Gall-Flies and Ichneumon-Flies. The gall-flies form many of the swellings on plants, known as galls. A common gall-fly of the oak (*Amphib'olips*) is shown in Fig. 48. The gall is caused by the female laying an egg in the leaf-tissue, which swells up when the larva hatches, owing, perhaps, to the presence of some irritating substance. The young feed on the material of the gall until they are ready to go into the pupal stage. Many of these galls harbor also guest gall-flies, living with the others as commensals.

Fig. 48. Gall-Fly. Natural size

Closely allied to the gall-flies are the ichneumon-flies, one of which, *O'phion*, is shown in Fig. 49. This species deposits its eggs in the burrows of a wood-boring larva by means of its long ovipositor, and the ichneumon larva on hatching moves along in its burrow until it finds its host, when it fastens itself to it and destroys it by sucking its blood. This carnivorous habit may be regarded as an approach to parasitism. Many of the ichneumon-flies are true parasites in the larval stage, the eggs being deposited on the skin or in the body

FIG. 49. Ichneumon-Fly. Natural size

of the caterpillars, upon the fluids of which the ichneumon larva feeds. The pupal stage is generally passed within the body of its victim.

Saw-Flies. The saw-flies differ from all the insects so far discussed in this chapter in having the base of the abdomen as broad as the thorax. The ovipositor of the female consists of a pair of saws, which are used to make slits in the leaves and stems of plants, in which she deposits her eggs. Fig. 50 shows the American saw-fly (*Cim'bex america'na*), our largest species. The larva looks like the caterpillar of a butterfly or moth, but has more legs. It has the curious habit of coiling the posterior end of its body about a branch, as shown in the illustration. It forms a brown cocoon in which the winter is passed in the ground. An Australian saw-fly is credited with staying with its eggs till they hatch, afterwards brooding over the young with outstretched legs, and protecting them by all the means in her power.

Definition of Hymenoptera (Gr. *hymen*, membrane; *pteron*, wing). The insects which we have been considering in this chapter all agree in possessing mouth-parts adapted both to

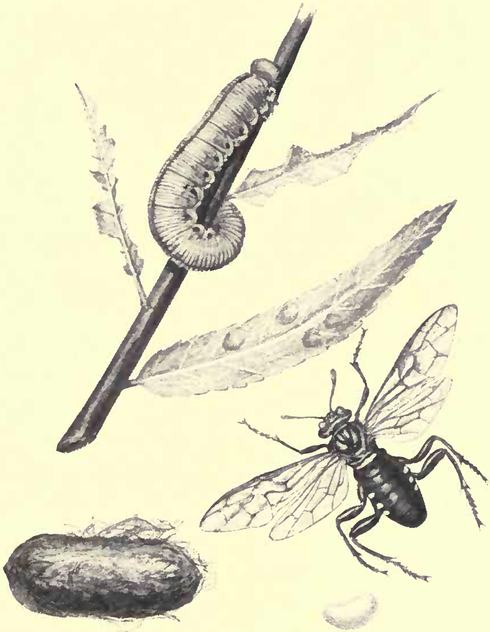


Fig. 50. Metamorphosis of Saw-Fly. Natural size

biting and lapping, and four membranous wings with few veins. The order is called *Hymenop'tera*. A structural peculiarity is the union of the first abdominal somite to the thorax, so that the division between what appears to be the thorax and the abdomen comes after the first abdominal somite. The Hymenoptera undergo "complete" metamorphosis. The larvæ are called maggots.

CHAPTER IX

THE INSECTS: HEXAPODA

> Though numberless these insect tribes of air,
> Though numberless each tribe and species fair,
> Who wing the moon, and brighten in the blaze,
> Innumerous as the sands which bend the seas;
> These have their organs, arts, and arms, and tools,
> And functions exercised by various rules.
>
> H. Brooke, *Universal Beauty.*

Definition of Hexapoda (Gr. *hex*, six; *pous* (*pod*), foot). The previous chapters have been devoted to entomology, that branch of zoölogy which treats of insects. The insects belong to the class *Hexap'oda*, the most numerous of all classes of animals, comprising four fifths of the animal kingdom. Insects are built externally upon the plan of a series of somites, grouped in three regions and with segmented appendages on two of them, — the head and thorax. Except in very few cases, where this number is reduced, the imagoes have six legs. Hexapods are found in every variety of situation, though they are, as a whole, adapted to life on the land and in the air. A system of tracheæ is universally present in the imagoes, though the young of some species have tracheal gills for breathing in the water.

The hard chitinous covering (exoskeleton) necessitates frequent molts to provide for increase in size. The molts may or may not be accompanied by metamorphosis. The most marked change of form is seen in the Coleoptera, Lepidoptera, Hymenoptera, and Diptera. In the first three of these orders, and in some Diptera, while the change in external form is often considerable, most of the larval organs persist in the imago, even though they undergo considerable modification in the process of transformation. In that division of the Diptera represented in our account of the order by the house-flies, flesh-flies, bot-flies, and hover-flies, the change from the larva to imago is so complete that nearly all the larval organs are disintegrated and the organs of the imago are built from separate masses of cells (imaginal disks or buds) which alone escape destruction. The breaking-down of the larval tissues is due to the activity of certain white blood-cells called *phagocytes* (voracious cells). It has been suggested that the escape of the imaginal disks from the general destruction is due to the fact that these masses of cells alone remain functional during the transition period between larva and imago.

All through the class a division of labor has been reached, in which the young feed and build up the material for the imagoes, which reproduce the species.

Instinct and Intelligence in Insects. Some of the most interesting questions in zoölogy are those dealing with the various reactions of animals to external objects, — the general subject of the behavior of animals. Some actions we explain as due to instinct, others we say are accompanied by intelligence, and still others we believe to be governed by reason. There is the widest possible difference of opinion among naturalists as to the relative importance of each of these in the life of the lower animals. Indeed, there is as yet little uniformity in the definition of the terms themselves, so that in our discussion of this subject in the class of insects we shall follow Professor Lloyd Morgan, of England, in his book, *Animal Behavior*, by defining as instinctive those acts which are similarly performed by all the members of a group of animals; which are, on their first occurrence, independent of experience; and which tend, usually, to the well-being of the individual and the preservation of the race. The act of the newly hatched larva of the milkweed-butterfly in devouring its egg-shell would therefore be called instinctive, as would the behavior of Pronuba in pollinating the yucca.

Dr. and Mrs. Peckham, in their work, *The Solitary Wasps*, from which we have quoted before, enumerate eight primary instincts:

1. Stinging.
2. Taking a particular kind of food.
3. Method of attacking and capturing prey.
4. Method of carrying prey.
5. Preparing nest and capturing prey, or the reverse.
6. The mode of taking prey into the nest.
7. The general style or locality of nest.
8. The spinning or not spinning of a cocoon, and its specific form when made.

Some instincts seem to be little more than direct responses of the nervous system of the animal to external exciting causes (see paragraph on reflex action, Chapter XVI, p. 208). Thus it is well known that moths and some other night-flying insects show a positive reaction toward light, which, under certain conditions, may tend toward the destruction of the insects, as may be seen about electric arc-lights in city parks in summer. The blow-fly is attracted to the decaying meat in which it lays its eggs by the chemical substances given off, which are perceived by the fly's sense of smell. Experiments on certain caterpillars seem to show that their life is largely determined by their positive reaction to light, their negative reaction to gravity, — these two combining to compel the caterpillars to crawl upward, — and a contact reaction with the convex terminal buds, tending to hold the caterpillar in place when at the end of twigs. When branches were inverted and placed in a receptacle in which certain caterpillars were, the latter remained at the top of the twigs, though food was only a few inches away, showing that the caterpillars were not normally attracted to their feeding-place at the ends of twigs merely by the presence of food there.

Actions which are due to the results of individually acquired experience, and which are performed without reflection or deliberation as to the means to be employed, or knowledge of the end to be reached, are termed intelligent actions by Professor Morgan. The behavior of that particular Ammophila observed to make use of a stone to pound down the sand over her nest may be called intelligent, using the word in the sense just defined. The power possessed by the honey-bee, bumblebees, and other Hymenoptera, of finding their way back to the nest, often from a considerable distance, may be dependent on a knowledge of the locality acquired in their various trips. If so, it would be an example of an intelligent action. Many of the habits of ants already described should probably be included here.

The word "intelligent" is commonly used to cover another and quite different class of activities, which demand separate consideration. To those activities which are guided in accordance with a plan which takes into consideration both the question of means to be employed and the end to be reached Professor Morgan applies the term "rational." Thus, a man in attempting to cross a swollen brook will consider the possibility of leaping, wading, or swimming across; or he will look about for material to make a bridge, noting the position of stones which might serve for supports, and considering, perhaps, the possibility of piecing together two short boards to make one board long enough for his purpose. When action is finally taken it is the result of a carefully considered plan. An example of this class of actions cannot be given from the insects, as we have at present no satisfactory evidence that the behavior of any insect ever rises to the rational plane.

In the discussion of this question it must not be forgotten that instincts are not fixed and unalterable, but that they are constantly being modified by new experiences. Therefore many of the actions of animals should not be classified as purely instinctive or purely intelligent, for they may contain elements of both factors. The words "instinctive" and "intelligent" can only be used to denote an apparent preponderance of one or the other factor. This is well illustrated by the observation Professor Morgan quotes from M. Fabre, who "describes how a *Sphex*, one of the solitary wasps, instinctively draws its prey, a grasshopper, into the burrow by its antennæ. When these were cut off the wasp pulled the grasshopper in by the jaw appendages; but when these were removed she seemed incapable of further accommodation to the unusual circumstances." Here we see not only obedience to a strongly marked instinctive tendency, but also some power to modify the instinctive reaction. It seems strange to us that if the wasp were capable of making this deviation from her instinctive mode of procedure, she should not take the slight further step of seizing upon the fore legs.

Another caution must also be stated. The distinctions already made assume that we are able to determine the mental states of animals; but this is true only in a very general way. We interpret the mental state of human beings by inference from their actions, but with the lower animals we have no positive means of knowing what mental state accompanies any given action, since their physical organization is so different from ours. And not only is this true, but we also lack a language to express the facts we observe concerning the mental life of the lower animals, since the words we use have their meaning in connection with the facts of human psychology.

Economic Importance of Insects. According to the report of the Secretary of Agriculture for 1902, the fixed capital of agriculture in the United States amounted in 1900 to twenty billions of dollars, or four times the amount invested in manufactures. More than half of the people of the United

States live on farms. When it is considered that our crops are attacked not by one but often by many different insects, and that, according to the estimate of one of the state entomologists of New York, there is no crop cultivated which infesting insects do not diminish by at least one tenth, it is plain that the economic relations of insects to agriculture are extremely important. Nearly every order has its injurious forms. Thus the Orthoptera has its locusts; the Hemiptera, the plant-bugs and aphids; the Coleoptera, the wireworms and leaf-beetles; the Diptera, various flies; while almost the whole army of the larvæ of the Lepidoptera feed on plants.

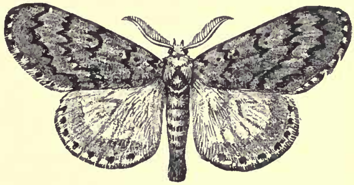


Fig. 51. Gypsy-Moth. Natural size. (After Howard, *Bulletin No. 11*, n.s., United States Department of Agriculture, Division of Entomology)

The story of the introduction and spread of the gypsy-moth of Europe (*Porthet'ria dis'par*, Fig. 51) in Massachusetts, teaches an important lesson. This insect, long well known by European foresters as destructive, was probably introduced in 1869 by a professor connected with Harvard Observatory, who was interested in breeding silk-producing insects. The larvæ escaped into his garden at Medford, near Boston, and though search was made for them, not all were found. Nothing was heard from them for fifteen years, when they began to be troublesome in gardens. By 1889 they had multiplied to such an extent that they attacked every green thing, and the bare branches of trees in every direction gave evidence of the extent of the devastations. In this year the insect was identified. Up to that time it had been called simply "the caterpillar." First the town of Medford, and then the state, took up the matter, and the first state appropriation of twenty-five thousand dollars was passed. Since that time additional appropriations have been called for, till seven hundred and seventy-five thousand dollars have been spent in a territory comprising about two hundred square miles. The end is not yet, for Dr. Howard, chief of the Division of Entomology, United States Department of Agriculture, in his report on *The Gypsy Moth in America*, from whose paper these facts have been taken, says that appropriations must continue for several years in order to exterminate the insects.

The Division of Entomology of the United States Department of Agriculture has been the means of saving large sums to the agricultural interests of the country by its various activities, such as the importation from other countries of beneficial species and its study of the habits of insects to find the best method of attack. Many of the states maintain boards of agriculture which employ entomologists.

The cotton-boll weevil (*Anthon'omus gran'dis*) has recently become a serious menace to the cotton industry of the southern states. The weevils are beetles possessing a long snout; this organ is often used by the female for piercing the tissues of plants to deposit her eggs. Among the weevils are many formidable enemies of the farmer. In this particular case the cotton industry has in some places been threatened with practical extinction. The Division of Entomology has been unremitting in its effort to find means to check the ravages of this weevil.

The relations recently discovered between some of the Diptera and disease must not be overlooked in considering the influence of insects on man, outside of his interests in agriculture.

Among beneficial insects may be mentioned the parasitic ichneumon-flies among the Hymenoptera, and the carnivorous lady-beetles and many ground-beetles among the Coleoptera. Comparatively few insects are directly useful to man; among such may be mentioned the silkworm, honey-bee, cochineal-insect and lac-insect.

Relations between Insects and Flowers. In order to make seed, the flowering plants require to have the pollen furnished by the stamens (Fig. 52, 1) carried to the pistil (Fig. 52, 2) of the same kind of plant. The pollen is necessary to the fertilization of the ovule (Fig. 52, 3), which afterwards grows into the seed. Continuous pollination of a plant by pollen which it furnishes from its own stamens has been found to be detrimental to the vigor of the seeds. We find in nature many devices to insure fertilization by pollen from another plant of the same kind, that is, by cross-pollination.

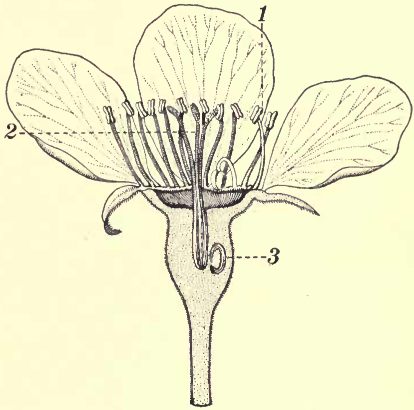


FIG. 52. Diagram of Pear Flower. (After Waite, *Year-book*, United States Department of Agriculture, 1898)

1, stamen; 2, pistil; 3, ovule

Some plants have the stamens and pistils so placed in the flower that no pollen can fall from one to the other; some ripen their stamens and pistils at different times. Many have the stamens and pistils on separate plants, and a great number, though the stamens and pistils are close together, are wholly or partially sterile to their own pollen, and "set" their seeds only if the pistils receive pollen from the stamens of another plant of the same species. This is the case with many of the fruit trees.

The wind carries pollen for some plants which have their stamens and pistils more or less exposed, but a great number of plants, especially those with the most beautiful flowers, depend on insects to bring about pollination. So far has this dependence gone that, in many cases, plants have become unable to pollinate themselves. It is now clear that the color, scent, nectar, and in many cases the form of flowers have been developed in connection with their insect visitors. The insects most concerned in the pollination of flowers are flies, butterflies, wasps, and bees.

Some insects visit flowers for the sake of the nectar. Pollination results from the insect brushing itself against the pollen-bearing organs and subsequently rubbing this pollen on to the pistil in a neighboring flower in the search for nectar. But the case of *Pronu'ba* (Fig. 53) is somewhat different. Pronuba is a white moth a little over a centimeter (about half an inch) long, which lives in the flower of the yucca, or Spanish bayonet, a familiar plant of the dry southwestern plains. During the day the female remains quiet, but at dusk (in the breeding season) she begins laying her eggs within the pistil of the flowers, among the ovules, which, when the flower is fertilized, are to grow into seeds. Upon these seeds the larva of the Pronuba will feed. If this were all, there would be no peculiarity deserving of mention; but the female goes a step farther and makes sure of a supply of seeds for the larva by collecting pollen from the stamens and thrusting it into the pistil. The advantage to the larva is obvious, since its supply of food is rendered certain; the advantage to the plant probably lies in the fact that not all the seeds thus provided for are eaten by the larva before reaching maturity. This association may be cited as an illustration of symbiosis.

FIG. 53. Pronuba Moth. Natural size. (After Riley)

Geographical Distribution of Insects. The map on page 17 shows the region of the United States occupied by the Rocky Mountain locust. Within a portion of this area the species is able to maintain itself permanently; just outside of this area are other regions which are only temporarily occupied, as the great swarms forming periodically seek a new home. That the species is able to maintain itself in one region and not in another is due to its adaptation to a particular region in the matter of food, temperature, climate, absence of overpowering enemies, and other causes. Similar maps might be drawn showing the geographical distribution of all the other insects studied. In each case there would be found some reason why a particular insect did not occupy a larger territory, since, generally, species tend by natural increase to broaden their ranges till hindered by some barrier to their farther advance. To land animals such barrier may be a mountain range, a desert, or a large body of water. To a desert-inhabiting species it might be a forest. To aquatic animals, waterfalls or rapids are often insurmountable. Temperature conditions are very definite in their effects on the distribution of animal life. Food-supply is another important factor. The ocean is a barrier to nearly all land species.

The animal life of any region is known as its fauna. Though insects are widely distributed over the earth, a study of the different species shows that there are more or less well-marked areas, each of which possesses its characteristic species. Though much overlapping occurs, as might be expected in the case of animals which can fly freely from place to place, yet on the whole it is possible to separate fairly well-marked regions, the climatic and other boundaries of which have prevented any great intercommunication, thus producing peculiar forms of life in each region. These regions may be stated as follows.

The *Arctic realm* includes all the land in the northern hemisphere as far south as the northern limit of trees and (so far as the insects are concerned) the tops of high mountains in the temperate zone. It has already been noted that the White Mountain butterfly (p. 48) belongs to this fauna. The *Eurasian realm* comprises all of Europe south of the Arctic realm; Asia, north of the Himalayas and south of the Arctic realm; and Africa, north of the Desert of Sahara. United with this, by many authors, is the *North American realm*, embracing North America south of the Arctic realm and north of Mexico. In past time land connection was more complete than at present, and considerable migration has taken place from one continent to the other. The *South American realm* comprises that portion of the continent north of Patagonia, and includes the West Indies, Central America, the greater part of Mexico, and a portion of the most southerly part of Florida. This region has contributed many species to our own fauna. South of this realm is another temperate region in Patagonia, which corresponds in position to the North American realm, but owing to its comparatively small size it is not usually ranked among the great regions of the earth. Its fauna is mainly derived from the South American. Still farther south is an Antarctic region of eternal snow and ice; but little is known of the life of this region, and it may be omitted from the list of the great faunal divisions. The *African realm* includes all Africa south of the Desert of Sahara. With this is often united the *Indian realm*, comprising the Asian continent south of the Himalayas, and the East Indies as far as the Strait of Lombok. The testimony of geology is strong that these two realms were once connected, though the water is now very deep and wide between them. Madagascar is by some naturalists included within the Indo-African realm; by others, considered a separate region. The last of the great faunal divisions is the *Australian realm*, including Australia, Papua, Celebes, and Lombok, and neighboring islands in the Pacific Ocean. It seems to have been isolated from the other land masses for a considerable period; it is singularly deficient in the highest forms of life. Each of the great faunal divisions is capable of subdivision, but into the details of this we need not go.

Nomenclature and Classification of Insects. In order to write intelligently about animals, it is necessary that naturalists should have some uniform system of naming, or nomenclature, since the common names of animals vary not only in the different countries and languages but even in different parts of the same country. It will be noticed that each insect, when first spoken of in these chapters, is accompanied by a scientific name printed in italics. Thus the Rocky Mountain locust is *Melanoplus spretus;* the common red-legged locust, *Melanoplus femur-rubrum;* the lesser locust, *Melanoplus atlanis.* These different kinds or *species* of locust differ in size, color, and habitat, and they each receive a different specific name, as *spretus*, *femur-rubrum*, and *atlanis.* They agree in other characteristics, such as the general structure, size, and proportion of their parts, and they are therefore placed in the same group or *genus*,—*Melanoplus.* The word "genus" is thus seen to be a term of wider application than the word "species." A genus may include one or several species. The generic and specific names make up the complete scientific name of an animal. The names are always taken from the Latin or Greek, or are Latinized in form, so that they are understood by all scientific men. They often refer to some striking characteristic of the animal; thus, *Melanoplus* means "black armor," in allusion to the dark-colored exoskeleton. Sometimes the reference is to the locality where the animal is found, as *atlanis*, referring to the Atlantic states; sometimes the name is given in honor of some student of animals, as *Darwin'ii* (see p. 343), named after the naturalist, Charles Darwin. The scientific name first given to an animal, if accompanied by a description, is the name it must bear, and the species is known under that name wherever found. This system of nomenclature was introduced by Linnæus (see p. 443).

We must not overlook the fact that in the study of animals we have to deal only with individuals. The words "species," "genus," and the other words used beyond, are man's invention, for his convenience in scientific description. Individuals which resemble each other in a large number of characters — and especially if the individuals are able to interbreed — are usually said to belong to the same species. The test of interbreeding, while of almost universal application, is not invariably a means of distinguishing the species, since in some cases two different species can produce offspring (called hybrids), though the latter are usually not fertile, — that is, they are not themselves capable of producing young.

Often within the limits of a single species there are groups of individuals which vary from the others in one or more characters. Especially is this true of those species with a wide range, including different climatic conditions. In such cases the different forms which the species assumes are termed *varieties*, and a varietal name is sometimes added to the generic and specific names. We have already referred to the seasonal variations of the black swallow-tail butterfly.

The different genera are arranged in groups, or classified, according to their resemblances and differences. A number of genera which show similar structural characteristics of more general character than those used to constitute a genus make up a *family*. Thus the locusts, not only of the genus *Melanoplus* but also of all the other genera found in North America, together with the genera of the Old World, have short antennæ, in common with other characteristics, which cause them to be placed in the locust family, *Acrid'idæ*. Similarly, the katydid and other green grasshoppers, with many meadow species, belong to the family of long-horn or true grasshoppers, *Locust'idæ*. The crickets (*Gryl'lidæ*) and the cockroaches (*Blat'tidæ*) are allied families. By common consent family names end in *-idæ*. Families are united to form *orders*, and orders in turn make up *classes*. The largest and most important of the orders which make up the class Hexapoda have already been discussed. As we shall see later, the classes are united to form *phyla* (sing., *phylum*), the primary divisions of the animal kingdom.

Definition of Thysanura (Gr. *thysanos*, fringe; *oura*, tail). Of the orders not mentioned in the preceding chapters it will be necessary to refer only to the *Thysanu'ra*, or springtails. The springtails are small, flattened, wingless insects, with usually simple eyes, and appendages on some of the abdominal somites. They are found under stones, in damp places, or in human dwellings. They develop from the egg without metamorphosis. The best-known species is the "silverfish," or "fishmoth" (*Lepis'ma saccharí'na*, Fig. 54), often seen in houses, where it sometimes does damage to starched clothing or to the bindings of books.

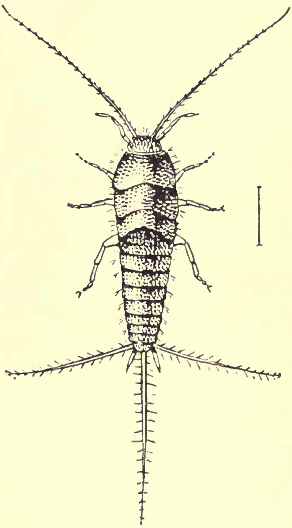


FIG. 54. Fishmoth. Enlarged. (After Marlatt, *Bulletin No. 4*, N.S., United States Department of Agriculture, Division of Entomology)

Generalized and Specialized Forms. The Thysanura are especially interesting, since they probably more closely resemble the ancestral type of insect than do any other living species. The primitive or ancestral forms were probably naked, wingless hexapods, without strongly marked divisions into head, thorax, and abdomen. Their legs were probably equal or nearly equal in size. The species probably developed from the egg without metamorphosis. The lack of special adaptations or modifications of the various organs marks the ancestral insects as *generalized* forms, as distinguished from their more or less *specialized* descendants of to-day, in which the organs have become modified to perform different functions. Thus the greatly developed hind legs of the locusts are a specialization in structure, fitting the insect to progress by leaps as well as by walking.

Very different degrees of specialization often exist in the organs of the same species; thus the digestive system of the locust is quite complex, while the separate prothorax is a generalized character, which shows the locust to be allied in this respect more closely to the primitive type than are insects like the wasps, for example, where the three divisions of the thorax are grouped in one mass. Within the limits of every order there are different degrees of specialization, and there are cases in every order where loss or decline of parts (called degeneration) has been brought about through various causes. Among the May-flies the mouth-parts of the imago have become degenerate in connection with the short adult life, which lasts only long enough for mating and the laying of eggs for a new generation. In some scale-insects the female becomes degenerate in connection with the quiescent life beneath a protecting scale. She loses eyes, antennæ, and legs, becoming very little more than a bag capable of feeding and reproducing. Parasitism also brings about degeneration.

From the study of the forms in which different organs appear in the orders of insects (that is, from the study of morphology, the science of form) the naturalist is able to say which kinds of insects have, on the whole, become most specialized in structure, and those which have, on the whole, varied least from the primitive generalized type. The evidence from this source points to the fact that the more generalized of the orders which we have mentioned are the Thysanura, Plectoptera, Odonata, Orthoptera, and Hemiptera. These are the orders, it will be remembered, in which metamorphosis is either entirely wanting, or where, if present, there is usually no well-marked pupal resting-stage.

In addition to morphology, another source of information is the geological record of species, — the fossil remains of organisms preserved in the mud, clay, or sand at the bottom of water. Wherever areas of land are uplifted, the atmospheric agencies of wind and water begin their work of wearing them down again. The worn materials in the form of clay, sand, or mud, as may be seen to-day after a rain, find their way in rivulets to lower ground, or into a river, which deposits them still lower, finally even to the bottom of the sea. When there, or in a temporary resting-place in some lake or pond, the material forms a bed into which the remains of animals may drop. Under favorable conditions their hard parts are preserved in perfect form, but the substance in them is replaced by minerals, and the entire mass is consolidated into rock by heat and the pressure of other materials upon it. Footprints may also be made in the soft mud at the edge of ponds, and indelibly preserved in the rocks of later times.

The geologist has worked out in detail the order in which the rock material of the world has been laid down. By studying the fossil remains of living things the zoölogist can picture something of the life of each of the great epochs in the earth's history, though owing to the conditions of preservation, by far the greater part of the record has been lost. It is as though we should try to get a connected idea of the history of the United States from a book from which had been torn the whole of the early voyages, much of the colonial period, and many pages from the story of the Revolution, the Civil War, and later history. Unfortunately the geological record is especially incomplete with regard to the insects, so that it does not give us much help in this particular problem. However, of the remains of winged insects which have so far been discovered, the earliest are those belonging to the orders Orthoptera, Hemiptera, Plectoptera, and Odonata.

A third source of information comes from the study of the earlier, or embryological, stages in the development of the individual. According to von Baer, a Russo-German naturalist born in 1792, the more nearly alike two animals belonging to the same phylum are, the greater will be the resemblance in their embryological stages; that is, the longer will the animals continue to follow a similar line of development. This is known as von Baer's law. Since his time the theory has been advanced that each individual animal, being the product of its ancestors, reproduces to a greater or less extent the stages which have occurred in the history of the race. According to this view the earlier stages in the history of the individual represent adult stages in the life of the past. This is known as the recapitulation theory. This principle applied to the cockroaches (see p. 20), would indicate their descent from ancestors which were more cylindrical than the flattened forms of to-day.

The conclusions of embryology justify the general statements just made, so that it is possible to assert that the orders without strongly marked metamorphosis are, on the whole, the "lower," or more generalized, insects; while the orders with marked ("complete") metamorphosis represent the "highest," or most specialized, types of the class to-day. The sequence in which the different orders of insects have been described in these pages represents, on the whole, with the exception of the Thysanura, a gradually ascending series from the more generalized forms to the highly specialized Lepidoptera, Diptera, and Hymenoptera.

CHAPTER X

THE DOCTRINE OF EVOLUTION

To the open ear it sings
Sweet the genesis of things,
Of tendency through countless ages,
Of star-dust and star pilgrimages,
Of rounded worlds, of space and time,
Of the old flood's subsiding slime,
Of chemic matter, force and form,
Of poles and powers, cold, wet, and warm.

EMERSON, *Wood Notes.*

Definition of Evolution. The word "evolution," in its most general sense, signifies a process of unfolding or development, and it is in this sense that we speak of the evolution of a plan or the evolution of history. In science, generally, the word is used to express the process of development from simplicity to complexity; that is, in the words of the Century Dictionary, "to a nicer and more elaborate means for reaching definite ends, the process being regarded as of the nature of a growth." In this sense we speak of the evolution of our solar system from a mass of heated gaseous material (see p. 293). In biology (the science which has to do with living things, — both plants and animals) the word is used not only to signify the development of an individual organism from the egg to maturity, but it serves to characterize a particular view as to the derivation of all organisms by natural descent, with modification of earlier and simpler forms of life. Biologists are generally agreed that all the many species of animals and plants of to-day have come to their present form through evolution, though the steps by which this evolution has been accomplished are not thoroughly understood. A classification of animals is not a mere grouping of species which resemble each other to a greater or less extent, but is rather an attempt at a statement of the truth of evolution, aiming to express the relationships existing between animals, as shown not only in their present structure but also by their development from egg to maturity, and their history through geological time.

While every species of animal tends to produce young resembling itself, no two individuals of any species are ever precisely alike. That the young of each species tend to resemble their parents, we say is due to *heredity;* that they never exactly resemble them, we say is due to *variation.* Of the causes underlying heredity and variation we know almost nothing. We notice that in the course of time various forms of life have appeared on the earth, and that on the whole there has been a gradually increasing complexity in animal structure through geological time, the more complex animals following the simpler, as the environment has changed and new conditions have arisen. Because of the incompleteness of the knowledge of the evolution of life on the earth, we can do little more than call attention to some of the secondary factors in evolution, without attempting to measure, except in a rough way, their relative importance.

Natural Selection. With the principle of natural selection are associated the names of Charles Darwin and Alfred Russel Wallace, who independently stated it in papers published in 1858 (see p. 450). The principle had been recognized before, but as stated by Darwin it was reënforced by such a wealth of illustration that it compelled the attention of the scientific world.

In introducing the discussion of natural selection, Darwin makes use of the principle of artificial selection among domesticated animals, — that is, the selection by man of certain individuals having peculiarities which he wishes to preserve. These individuals are allowed to breed together, and, in the next generation, those individuals varying in the direction desired are again chosen for breeding. If the process is continued through several generations it may produce a race in which the special characteristic desired is fixed. Artificial selection is one of the means by which the different races of domesticated animals and plants have been produced.

According to Darwin, something similar to this artificial selection by man goes on in nature, producing the different species of animals as we know them to-day. All organisms tend to vary. Some variations, he says, are due to changes in the conditions of life and to excess of food (these two underlying the great variability of domesticated animals); others are due to the nature of the organism; to the inherited effect of habit and the use and disuse of parts; or to reversion to characters once possessed by ancestors. The variations which occur are of two kinds, — definite and indefinite. Indefinite, or fluctuating, variations are those comparatively slight differences which occur constantly among animals and plants, so that of all the individuals of the same species, no two are ever exactly alike. Definite variations are more striking; of these the ancon ram is an example. This animal, born in Massachusetts in 1791, of an ordinary breed of sheep, had a long back and short, crooked legs. From it, by crossing, has been produced the ancon breed of sheep, showing the same peculiarities as its progenitor. The breed was highly prized for a time on account of the inability of the animals to jump fences. Darwin lays most stress upon the fluctuating variation as affording the material for natural selection.

In order to understand the principle of natural selection, we must consider for a moment the struggle for existence. This term is used by Darwin in "a large and metaphorical sense, including dependence of one being on another, and including (which is more important) not only the life of the individual but also success in leaving progeny." The struggle results from the tendency of living things to increase more rapidly than the means of subsistence. Professor Jordan, of Leland Stanford Junior University, says, "If the eggs of a common house-fly should develop, and each of its progeny should find the food and temperature it needed, with no loss and no destruction, the people of a city in which this might happen could not get away soon enough to escape suffocation from a plague of flies." Professor Thomson, of Edinburgh, Scotland, gives this illustration: "A female aphis, often producing one offspring per hour for days together, might in a season be the ancestor of a progeny of atomies which would weigh down five hundred

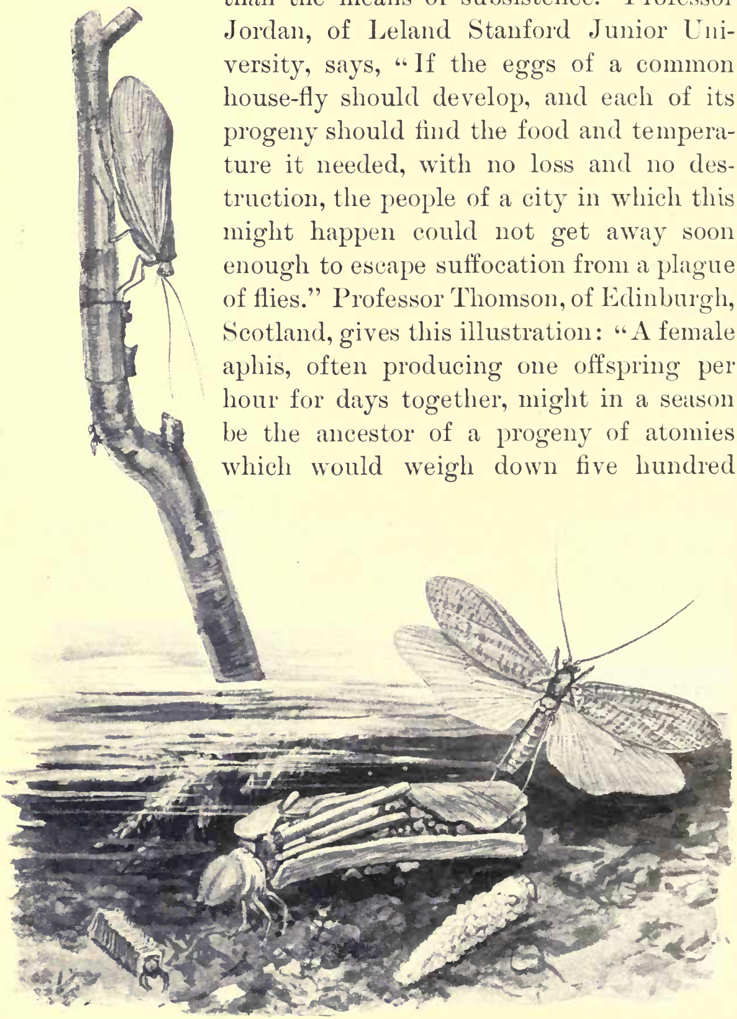


FIG. 55. Caddice-Flies. Enlarged

millions of stout men." A similar rapid increase would be noted on the part of any animal, were the various checks to its multiplication removed. The struggle for life goes on between different individuals of the same species, as in a swarm of locusts; between individuals of different species, as with locusts and insect-eating birds, and with the conditions of existence, such as temperature, winds, moisture, and food-supply.

Owing to the struggle for existence, Darwin says: "Variations, however slight, and from whatever cause proceeding, if they be in any degree profitable to the individuals of a species, in their infinitely complex relations to other organic beings and to their physical conditions of life, will tend to the preservation of such individuals, and will generally be inherited by the offspring. The offspring, also, will have a better chance of surviving, for, of the many individuals of any species which are periodically born, but a small number can survive."

The caddice-flies are, in their immature stage, aquatic larvæ which build protective cases composed of grains of sand, or bits of straw, or leaves (Fig. 55). These cases afford concealment and protection to the young. Applying the principle of natural selection here, it would be said that those caddice-flies which varied in the direction of protective cases have survived, and those which did not have been devoured or otherwise destroyed; hence a race of case-building caddice flies is in existence to-day. Natural selection results in "the survival of the fittest" for the environment, and the principle is used to explain the degeneration due to parasitism, as well as the development of increased complexity in animal structure.

We have spoken of the conflict between individuals of the same species for the necessities of existence, but many species, individually rather weak, become successful competitors in the struggle for existence by mutual aid and coöperation. Prince Kropotkin has recently called attention to cases of mutual aid in the animal kingdom. He says: "As soon as we study animals — not in laboratories and museums only, but in the forest and the prairie, in the steppe and the mountain — we at once perceive that though there is an immense amount of warfare and extermination going on amidst various species, and especially amidst various classes of animals, there is, at the same time, as much, or perhaps even more, of mutual support, mutual aid, and mutual defense amidst animals belonging to the same society. Sociability is as much a law of nature as mutual struggle." Illustrations may be seen in the complicated communities of the ants, bees, and wasps among the insects; others occur among the birds and fur-bearing animals (see Chapters XXIX and XXXI).

Sexual Selection. The principle of sexual selection, also formulated by Darwin, is an extension of the principle of selection to account for the secondary sexual characters which exist in many animals. In most insects, where there is sexual dimorphism, the male, though usually smaller, is more brightly colored; it is armed or ornamented with spines, which the female does not possess, or it has special sound-producing organs. In the common stag-beetle (*Luca'nus*, Fig. 56) the mandibles of the male are of larger size than those of the female. Among the birds, in those cases where the sexes are differently colored, the males are usually more brilliant; they often have spurs, wattles, crests, or plumes, while the females are without these structures, or have them in less degree. It is only the male birds, too, which possess the gift of song. Among the fur-bearers special characteristics, such as horns, antlers, and tusks, often occur. These various secondary sexual differences are ascribed by Darwin to sexual selection, which "depends, not on a struggle for existence in relation to other organic beings or to external conditions, but on a struggle between the individuals of one sex, generally the males, for the possession of the other sex. The result is not death to the unsuccessful competitor, but few or no offspring. Sexual selection is, therefore, less rigorous than natural selection. Generally the most vigorous males, those which are best fitted for their place in nature, will leave most progeny. But in many cases victory depends not so much on general vigor

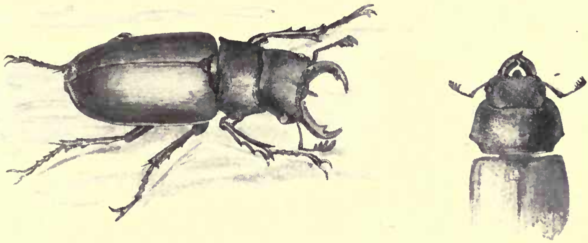


FIG. 56. Stag-Beetle (male and female). Natural size

as on having special weapons confined to the male sex. A hornless stag or spurless cock would have a poor chance of leaving numerous offspring." The greater brilliancy of many males is accounted for by ascribing it to the choice by the females, through countless generations, of the most brilliantly colored and attractive males. The song of male birds is accounted for in a similar manner.

The Inheritance of Acquired Characters. Though Darwin considered that species have arisen largely through the action of natural selection on favorable variations, he admitted also other factors in evolution, on which some naturalists to-day lay great stress. It is a truism of our everyday life that the use of an organ sooner or later affects its structure. Thus the brawny arm of the blacksmith may be directly attributed to the kind of work he does. There are many cases in the animal kingdom where the characters of animals might be interpreted as due to the use or disuse of organs. Among the insects we may instance the enlarged fore legs of the mole-cricket and mantids, the enlarged hind legs of the locust, and the absence of eyes in certain cave-inhabiting insects. With this principle are associated the names of Erasmus Darwin, grandfather of Charles Darwin, and the French naturalist Lamarck (see p. 448).

The chief difficulty in the application of the principle of the inheritance of acquired characters as a factor in evolution lies in the fact that we have little or no evidence that the characters acquired by use or disuse during the life of an individual are transmitted to its descendants, though some effort has been made of late years to furnish this direct evidence. The most important experiments along this line are those of Brown-Sequard, a Franco-American physiologist (1819–1894). He succeeded in producing epilepsy in guinea-pigs born of parents which had been rendered epileptic by an injury to the spinal cord. Exophthalmia (a disease characterized by abnormal protrusion of the eyeball) was also transmitted through several generations. Certain mutilations, produced by the animals eating off their hind-leg toes after the latter have been rendered insensible to pain by cutting the nerve leading to them, also seem in some cases to have been transmitted to the descendants. The objection is made to these experiments that they may show the result of a transmitted disease rather than the inheritance of an acquired character.

The Direct Influence of the Environment. In connection with the principle of the inheritance of characters acquired through use or disuse, Lamarck held that the changes in the environment directly brought about changes in the organism, and that these changes were transmitted to the descendants (see p. 449). This and the preceding principle are therefore often spoken of as Lamarckian factors in evolution, while natural and sexual selection are termed Darwinian factors.

All organisms have to exist under certain conditions of pressure either of liquids or gases; they are adapted to a certain range of temperature, moisture, and light; they require more or less oxygen; and they need a certain amount and quality of food. As a general rule slight changes in these various elements of the environment can be borne without injury; greater changes may cause death. There are a number of cases in the animal kingdom where modifications in the organism seem to be directly connected with environmental changes, though it is not always easy to say what factor in the environment is responsible for the change. Thus it has been stated that horses tend to decrease in size in northern latitudes, on islands, and on mountains. Most of the animals on islands are smaller than their continental relatives. De Varigny, in his *Experimental Evolution*, says that, "In the Canary Islands the oxen of one of the smaller islands are much smaller than those of the others, although all belong to the same breed; and the horses are also smaller, and the indigenous inhabitants are in the same case, although belonging to a tall race." The same author also cites the experiments of Karl Semper, who stated that if the common pond-snail of Europe is kept in small volumes of water, — less than five or six liters (a little over four or five quarts), — the animals do not attain their usual size, but remain more or less dwarfed. The differences between the geographical varieties of the gray squirrel are given on page 406. Among the insects the influence of food in the production of the queen bee, and the influence of temperature in the production of the different broods of one of the swallow-tail butterflies have already been commented upon. It has also been found that colored bodies in the vicinity affect the colors of the pupæ of certain butterflies (Fig. 57). Such color changes are due to the susceptibility of the larva to surrounding colors during a quiescent period before pupation. The experiments on *Arte'mia*, described on page 148, may also be referred to in this connection.

The difficulty in adopting this principle as an explanation of the way in which evolution has taken place lies in the fact already mentioned in the discussion of characters acquired through use or disuse, — that it is not yet entirely clear that changes occurring during the lifetime of the individual are transmitted to the next generation.

FIG. 57. Pupæ of Black Swallow-Tail Butterfly

Showing influence of color of near-by object on the color of the pupa. Photographed from life. About three quarters natural size

(From Hunter's *Studies in Insect Life*)

The Mutation Theory. It will be remembered that Darwin laid stress upon indefinite, or fluctuating, variations as furnishing the greater part of the material for selection. The mutation theory stands in sharp contrast with the selection theory in emphasizing the heredity transmission of definite variations. With the mutation theory is particularly associated the name of Hugo de Vries, a Dutch botanist living in Amsterdam, Holland. He was led to express the principle from his studies of the variations of a species of evening primrose introduced from America and found growing in waste places in Hilversum, near Amsterdam. It should not be overlooked that William Bateson, of Cambridge, England (born 1861), emphasized the evolutionary importance of discontinuous variations (mutations) years before de Vries' work appeared. One of the most recent general statements of the principle is to be found in *Evolution and Adaptation*, by Professor Thomas Hunt Morgan of Columbia University. From his book most of the following statements have been taken.

According to this principle new species have been produced by sudden and perfectly definite changes (mutations) in the organism, though it is not necessary to assume that these changes are always great. The theory makes no attempt to account for the presence of mutations, but when they occur it is a striking fact that the characters tend to be transmitted to the descendants. De Vries is inclined to think that there are periods of mutation when many and great changes take place, and periods where comparatively little change in the organism occurs. The same mutation may occur time after time and in large numbers of individuals. When a mutation appears its survival will depend on whether it can find a place in nature where it can exist and leave descendants. If the organism is well adapted to its environment, it will leave many descendants; if it is poorly adapted, it may barely succeed in existing. Useless or even slightly injurious characters may appear, and if they do not too seriously affect the perpetuation of the race, they may persist. Since the mutations appear fully formed, there is no difficulty in accounting for the early stages of an organ. Thus, on the supposition of natural selection, it is difficult to see, for example, how the first slight movement of the eye of the flounder toward the upper side (see p. 320) could be a favorable variation, which it should be according to the selection theory, in order to be preserved. Again, a difficulty in the selection theory lies in the fact that the differences between allied species consist largely in differences of unimportant organs, but this is the condition we should expect, according to the mutation theory.

Professor Morgan brings his discussion to a close by a statement contrasting the mutation theory with the selection theory, as follows: "Animals and plants are not changed in this or in that part in order to become better adjusted to a given environment, as the Darwinian theory postulates. Species exist that are in some ways very poorly adapted to the environment in which they must live. If competition were as severe as the selection theory assumes, this imperfection would not exist.

"In other cases a structure may be more perfect than the requirements of selection demand. We must admit, therefore, that we cannot measure the organic world by the measure of utility alone. If it be granted that selection is not a molding force in the organic world, we can more easily understand how both less perfection and greater perfection may be present than the demands of survival require.

"If we suppose that new mutations and 'definitely' inherited variations suddenly appear, some of which will find an environment to which they are more or less well fitted, we can see how evolution may have gone on without assuming new species have been formed through a process of competition. Nature's supreme test is survival. She makes new forms to bring them to this test through mutation, and does not remodel old forms through a process of individual selection."

Mendel's Law of Heredity. Considerable attention has lately been given to the experimental study of heredity and variation by breeding animals and plants under close observation. Among the animals thus observed have been mice, guinea-pigs, and rabbits. Little has been done along this line with the insects. These experiments have been of great interest in connection with what is known as Mendel's law.

Gregor Mendel was an Austrian monk, who experimented with plants in his garden, and in 1865 communicated to the Society of Naturalists at Brünn the substance of what has since been described as "the greatest discovery in biology since Darwin." As the result of later experiments the law was rediscovered by Bateson. In our own country Professor Castle, of Harvard University, has made observations on many successive generations of guinea-pigs, mice, and rabbits. The substance of most of the following statements has been taken from his studies.

Mendel's law asserts that when mating occurs between two animals differing in some character, the offspring (hybrids) will frequently exhibit the characters of one parent only. A particular character exhibited in that way is said to be "dominant." If albino rabbits (white, with pink eyes) are crossed with gray rabbits, all the offspring are gray, that color being dominant. The character (in this case, whiteness) which is not seen in the immediate offspring is said to be "recessive." That the albinism (white character) is really present in the second generation, although invisible, may be demonstrated by permitting pairs of these hybrid rabbits to breed. The principle may be called "the law of dominance." It does not seem to be of universal application, as sometimes the young have a character of their own. Thus, if a lop-eared rabbit is bred with a short-eared rabbit, the young will have ears of an intermediate length. There is no way of knowing what the character of the young will be; it can only be determined by experiment. When once determined, however, the character is always the same for every hybrid, provided the parents are of pure breeds.

The essential part of Mendel's discovery is this: that the hybrids resulting from the crossing of animals, such as white and gray rabbits already spoken of, whatever their own character, will produce ripe germ-cells (reproductive cells, see p. 210), which bear only the pure character of one parent or the other, but never both; and these will be produced in equal numbers. This is known as "the law of the purity of the germ-cells." From this law follows the occurrence in the next and succeeding hybrid generations of a definite number of forms in definite numerical proportions. Thus in the third generation of rabbits, produced by the breeding together of the progeny of the gray and the albino rabbits already referred to, there are, in nearly every case, three gray young to one albino. Results similar to these were obtained by Professor Castle with mice and guinea-pigs also.

The explanation of why a character may manifest itself in the third generation, after being invisible in the second, is to be found in the theory that characters of organisms are transmitted from generation to generation only in the germ-cells, and by extremely minute bodies, called chromosomes, within these cells. The second generation is all gray, because in the united germ-cells from male and female parents the chromosomes which bear the gray character are more powerful to express themselves in the appearance of the young which is produced than are those chromosomes which bear the albino character. However, the albino chromosomes are not destroyed, but are carried along with the others and give rise to other chromosomes of their own kind, until, in the experiment of breeding two hybrids, there occurs the opportunity for one albino germ-cell from each of the two sexes to unite and produce an albino young. The mathematical chances of such an occurrence may be expressed in an algebraic formula in which D represents dominant germ-cells (half the total number) and R represents recessive germ-cells (half the total number). A D-cell may unite with another D-cell, or it may unite with an R-cell. Similarly an R-cell may unite with an R-cell or with a D-cell, thus:

$$\begin{array}{ccc} D & \text{and} & R \\ D & \text{and} & R \end{array}$$

$$\underbrace{DD + 2\,D(R)}_{3} + \underbrace{RR}_{1}$$

Of the three dominant individuals one is a pure dominant, but it is impossible to say at first which one that is, except by further breeding. The pure dominant, when bred with another pure dominant, will produce only gray rabbits, and these will produce gray rabbits generation after generation. Albinos obtained in experiments like the one described will breed true generation after generation, if mated with other albinos. When one of the hybrid dominants, $D(R)$, is mated with a recessive animal, half the young are hybrid dominants and half are recessives. Two hybrids mated will produce young in the proportion of three gray to one albino, as in the third generation.

Experiments to determine the dominant or recessive nature of other characters, such as length of hair and smoothness of coat, show that short hair in guinea-pigs dominates over long hair, and a rough coat over a smooth coat. It is also true that the various characters, so far as tested, are inherited quite independently of one another. A smooth coat may be associated with white hair or with pigmented hair in guinea-pigs, and a rough coat also with white hair or with pigmented hair. An experimenter, by controlling the combinations of a number of characters, knowing which is dominant and which recessive, may produce several distinct types of animals within the same species.

If future experiments should support Mendel's law, we should then be able to understand how it is that races suddenly spring into existence in nature and become established.

CHAPTER XI

THE SPIDERS AND ALLIES (ARACHNIDA) AND THE CENTIPEDS AND MILLEPEDS (MYRIAPODA)

> A noiseless, patient spider,
> I marked where, on a little promontory, it stood isolated;
> Marked how, to explore the vacant, vast surrounding,
> It launched forth filament, filament, filament out of itself;
> Ever unreaching them — ever tirelessly speeding them.
>
> WALT WHITMAN.

Spiders. Spiders have several of the anterior somites joined into a single mass, the head-thorax, or *cephalothorax* (Fig. 58, 1), followed by the nearly spherical *abdomen* (Fig. 58, 2). The cephalothorax bears six pairs of appendages, — two pairs of the nature of jaws and four pairs of *walking-legs* (Fig. 58, 3). The *mandibles* (Fig. 58, 4), the first pair of jaws, are appendages composed of two segments, of which the terminal segment is sharp-pointed and hollow, for the passage of a poisonous secretion from a gland placed partly in the head and partly in the basal segment. The second pair of jaws, or *maxillæ*, bear jointed *palpi* (Fig. 58, 5), used for handling food. On the front of the head are eight *simple eyes;* compound eyes and antennæ are wanting.

Two little slits on the under side of the abdomen open into the *breathing-organs* (Fig. 58, 6), which consist of a pair of sacs containing a number of thin plates, like the leaves of a book, through which the blood passes for the exchange of gases. Between the two slits are the external openings of the *reproductive organs* (Fig. 58, 7). At the end of the body are three pairs of *spinnerets* (Fig. 58, 9), consisting of a number of little tubes leading from glands in the abdomen, which secrete a viscous fluid that hardens into silk on exposure to the air. Two *tracheæ* (Fig. 58, 8), which give off branches to different parts of the abdomen, open just in front of the spinnerets.

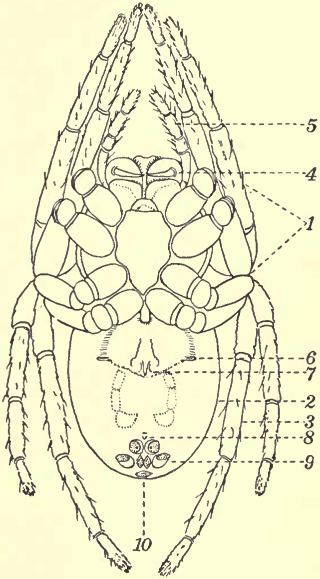


Fig. 58. External Anatomy of the Spider (*Epeira vulgaris*). Enlarged. (After Emerton)

1, cephalothorax; 2, abdomen; 3, fourth leg; 4, mandible; 5, palpus; 6, opening to breathing-organ; 7, openings to reproductive organs; 8, tracheæ; 9, spinnerets (3 pairs); 10, anus

Many spiders build circular webs of silk, in which they capture insects to suck their blood. A common species of garden spider (*Argi'ope ripa'ria*) is shown in Fig. 59. The spider first spins a line across the space where the web is to be, and then attaches near its center other threads, which it carries to different points, making the radiating foundation-lines of the web. These lines are all dry and inelastic. Concentric spiral lines of an adhesive nature are then added, the hind legs being used to place the threads, and an oval cover of silk is spun in the center, beneath which, or in a folded leaf at the side, the spider lurks in watch for its prey. A zigzag band of white silk crossing the center is usually added to strengthen the web. When an insect is captured the spider rushes out, and if there is any danger of the escape of the prey, it is deftly wound with more silk till its struggles have ceased. If it proves to be a wasp or other dangerous capture, or if it is too big to be safely managed, it is often assisted to escape by cutting the web, which is then repaired for another victim.

Like the click-beetles and many others of the Coleoptera, this spider when alarmed has the habit of dropping to the ground as if dead. It spins a thread of silk as it drops; when

Fig. 59. Garden-Spider and Web. Reduced

the danger is over it is able by this means to find its way back to the web.

The eggs are laid in the autumn in a sac of silk (Fig. 60), which may contain from five hundred to two thousand eggs. These eggs hatch early in the winter, and the young live in the case through the cold weather, feeding on each other, so that by spring a comparatively small number of spiders emerge. By successive molts, without marked metamorphosis, they reach their adult size.

The dark-colored, hairy spiders (*Lyco'sa*) found under sticks and stones usually build tubular nests in the ground, which they line with silk. They do not make a web to capture their prey, but spring upon it as they run about in search of food. The females may often be seen dragging after them the large gray ball which contains, at first, their eggs, and afterwards the young. After a certain time the young leave the silken case, and for some time longer run about over the body of the mother.

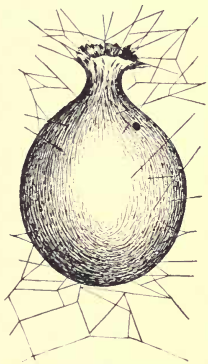


FIG. 60. Egg-Case of the Garden-Spider. Natural size. (After Wilder)

These spiders are often called tarantulas, but that name should be restricted to the large, hairy spiders of the warm parts of the world, which can be distinguished from all other spiders by the fact that the terminal segment of the mandibles works vertically instead of horizontally. Tarantulas are universally dreaded in the countries where they grow to be of large size, and they are believed to be very poisonous. The ability of any spider to pierce the human skin depends, of course, on its size and the strength of its jaws; the effect produced by the bite depends not only on the amount of poison injected into the wound but also on the age and mental and physical condition of the person bitten. Though many stories of death by tarantula bites have been told, most of them are clearly untrue.

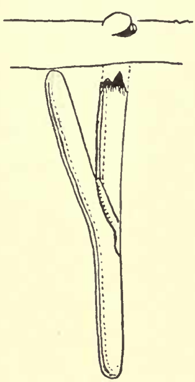


FIG. 61. Trap-Door Spider Burrow, showing Side Tube. Reduced. (After Emerton)

Persons have been bitten by them, and only temporary pain and swelling have resulted, something like that which follows the sting of a bee.

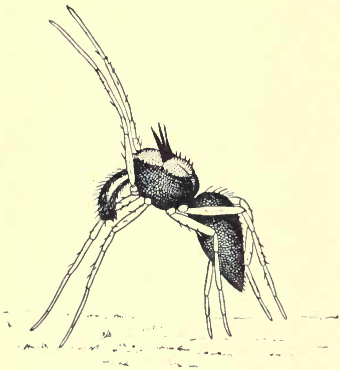


Fig. 62. Jumping-Spider. Enlarged. (After Peckham)

Among the most interesting of the tarantula family are the trap-door spiders of the western and southern states, and of southern Europe. They build burrows, which they line with silk, and provide with a lid lined with silk, attached by one edge to the mouth of the burrow. A European species builds a nest with a side tube (Fig. 61) into which it can retreat in time of danger, closing a door at the entrance of this tube.

The jumping-spiders (*As'tia vitta'ta*, Fig. 62) may be recognized by the stout, hairy body and the square head. They are usually conspicuously colored, and have bright, staring eyes. They build no webs to capture their prey, but spring upon it, often from a considerable distance. These spiders are interesting on account of the remarkable antics which the males perform before the females. Dr. and Mrs. Peckham, in their study of the habits of this group, say: "The fact that the males vie with each other in making an elaborate

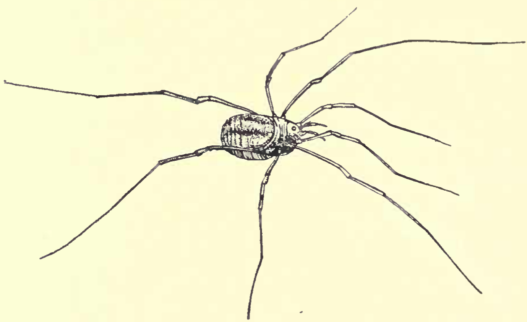
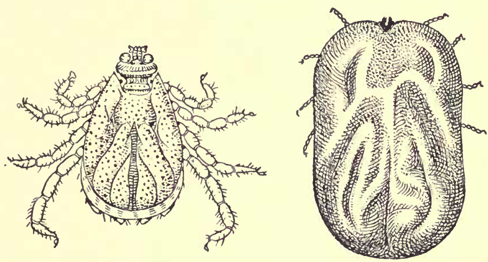


Fig. 63. Harvestman. Natural size

display not only of their grace and agility but also of their beauty before the females, and that the females after attentively watching the dances and tournaments which have been executed for their gratification, select for their mates the males that they found most pleasing, points strongly to the conclusion that the great differences in color and in ornament between these spiders are the result of sexual selection."

Harvestmen. The long-legged harvestmen, or daddy-long-legs (*Liobu'num*, Fig. 63), are allied to the spiders. They can be recognized by the eight extremely long legs, which are thus developed as organs of touch, as well as for walking. They are harmless creatures, found in damp and shady places; they feed on small insects, especially aphids.

Mites and Ticks. The mites and ticks are related to the harvestmen and to spiders. They show less segmentation of the body than the preceding groups. They are small, oval, eight-legged forms. The mouth-parts are more or less united to form a beak. Some are parasitic on other animals (*Ixo'des*, Fig. 64); others, like the common red mite which infests house-plants, suck the fluids of vegetation. One of them produces the disease known as mange, among dogs, horses, and cows.



A *B*

FIG. 64. Cattle-Tick. Enlarged. (After Howard, *Year-book*, Department of Agriculture, 1891)

A, parasite without food; *B*, parasite filled with blood from host

Scorpions. The scorpions have the body plainly segmented. In the common scorpion (*Bu'thus*, Fig. 65), found under sticks in our southern states, the maxillæ are greatly elongated, making a formidable-looking pair of claws. The abdomen is provided with a sting at its extremity. The whip-scorpion (*Thelyph'onus*), also found in similar situations in the South, is another formidable-looking creature, with immensely developed maxillæ, which are used to pull open decaying wood in search of small insects, which form its food. Its appearance accounts for the dread it inspires, but there is no evidence to show that it is harmful to man.

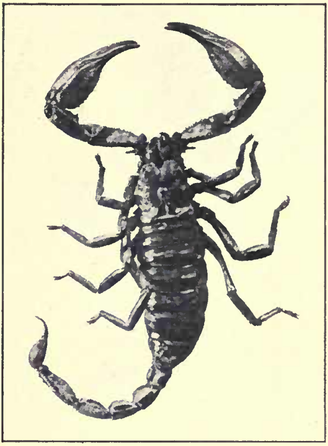


FIG. 65. Photograph of Scorpion. Natural size. (American Museum of Natural History)

Definition of Arachnida (Gr. *arachne*, spider). All the forms considered so far in this chapter belong to the class *Arach'nida*. The Arachnida agree in having the somites fused into two more or less clearly marked regions, the cephalothorax and the abdomen. There is no distinct head, as in insects. Eight legs are present. The Arachnida undergo no well-marked metamorphosis.

Centipeds. The common centiped (*Litho'bius*, Fig. 66) found under the bark of trees is an elongate, flattened animal, with long antennæ, many somites, and a pair of legs on every somite. There is a poison-gland in the base of the first pair of legs, which is used to kill earthworms and insects, upon which Lithobius feeds. The female is furnished with two hooks at the end of the body close to the oviduct. When an egg is laid it is seized by these hooks and rolled over till it is completely covered with earth, which adheres to the egg on account of a sticky substance with which it is covered. It has been observed that if a male Lithobius perceives the egg before it is disguised by the covering of earth, he attempts to seize and devour it.

Centipeds are widely distributed over the world. In the tropics they grow to be over thirty centimeters (one foot) long. Some species are poisonous, even to man, and death has been known to result from their bite. They are active

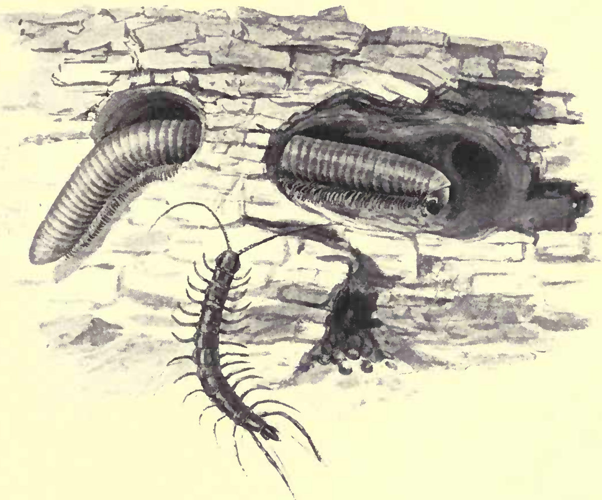


Fig. 66. Centiped and Milleped. Reduced

creatures, and feed on living animals. The number of somites varies from about nine to over two hundred. A pair of legs is attached to each somite. The following lines were written by Professor E. Ray Lankester, of England, after an attempt to study the order in which the legs were moved.

A centipede was happy quite
Until a toad in fun
Said, " Pray, which leg moves after which ? "
This raised her doubts to such a pitch,
She fell exhausted in the ditch,
Not knowing how to run.

Millepeds. Other elongate forms called millepeds (*Spirob'-olus*, Fig. 66) may be distinguished from the centipeds by the more cylindrical body. Millepeds also possess a greater number of legs than centipeds, each somite, with the exception of several coming directly after the head, apparently bearing two pairs of legs. They live in damp places and feed on living or decaying vegetable matter; they are entirely harmless. Many have the power of coiling themselves up when disturbed. The larvæ, when first hatched, have few somites, and but three pairs of legs.

Definition of Myriapoda (Gr. *myria*, many; *pous*, foot). The centipeds and millepeds are included in the class *Myri-ap'oda.* Myriapods are distinguished from insects and arachnids by the greater number of somites and appendages. They breathe through spiracles placed along the sides of the body. After hatching from the egg, the young develop without any marked metamorphosis. It is likely that centipeds and millepeds are not in reality as closely allied as might seem from the external appearance.

CHAPTER XII

THE CRAYFISH

All night the crawfish deepens out her wells,
As shows the clay that freshly curbs them round.

J. P. Irvine, *Summer Drought.*

Habitat and Distribution. Crayfishes, also called crawfishes, are found in bodies of fresh water on every continent except Africa, and in many of the large islands. The eastern American species, *Cam'barus af'finis* (Fig. 67), which grows to the length of five or six inches, may be taken as an example of the several genera and the many species which are known by the common name crayfish.

External Plan of Structure. The body, except for the ventral surface of the abdomen, is covered with a thick wall, formed, like the covering of insects, from the hardening of a secretion of the outer layer of the skin. Unlike the insects, this protecting sheath is filled with carbonate of lime. The body is divided into a *cephalothorax* and *abdomen* (Fig. 67, 1, 2), as in the arachnids. There are no indications on the dorsal surface of separate somites in the cephalothorax, but on the ventral surface transverse grooves and paired appendages indicate a division into thirteen *somites*. The abdomen (Fig. 67, 2) plainly consists of seven somites, of which the first six bear jointed appendages. The external plan upon which the crayfish is formed is similar to that of the insects, arachnids, and myriapods; that is, a series of somites placed one after the other, with all appendages jointed or segmented.

The Cephalothorax. The shell covering the dorsal and lateral surfaces is distinct from the hard parts elsewhere on the body, and is termed the *carapace*. At the anterior dorsal

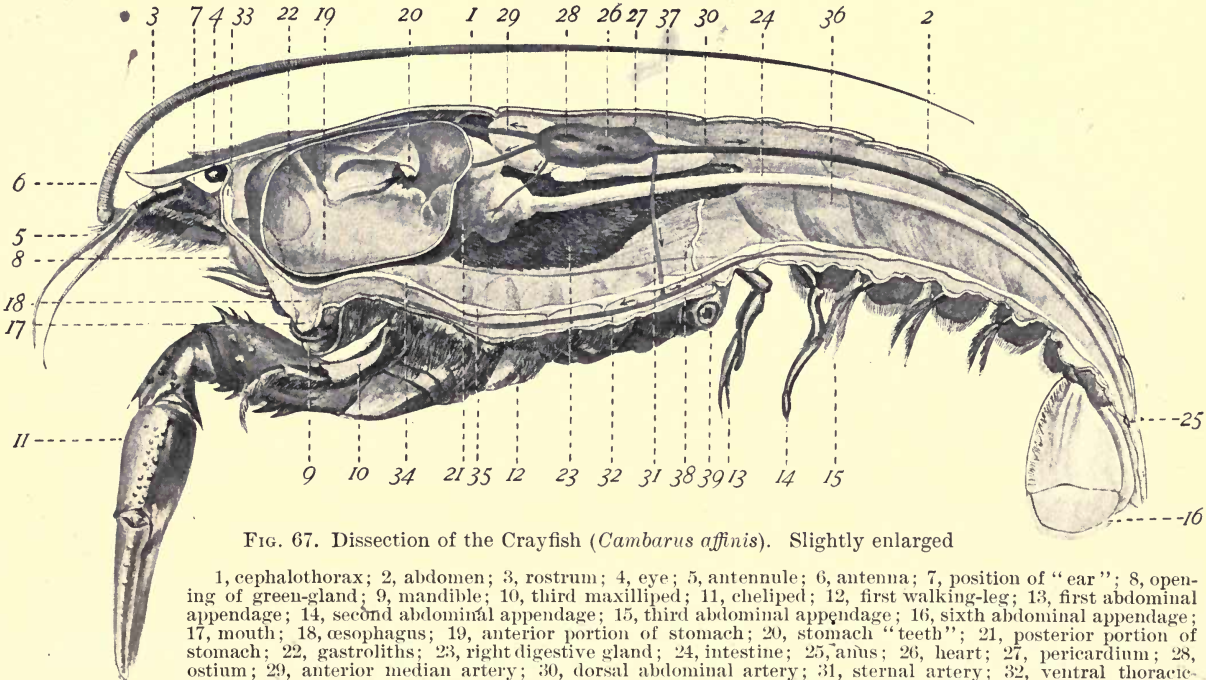


Fig. 67. Dissection of the Crayfish (*Cambarus affinis*). Slightly enlarged

1, cephalothorax; 2, abdomen; 3, rostrum; 4, eye; 5, antennule; 6, antenna; 7, position of "ear"; 8, opening of green-gland; 9, mandible; 10, third maxilliped; 11, cheliped; 12, first walking-leg; 13, first abdominal appendage; 14, second abdominal appendage; 15, third abdominal appendage; 16, sixth abdominal appendage; 17, mouth; 18, œsophagus; 19, anterior portion of stomach; 20, stomach "teeth"; 21, posterior portion of stomach; 22, gastroliths; 23, right digestive gland; 24, intestine; 25, anus; 26, heart; 27, pericardium; 28, ostium; 29, anterior median artery; 30, dorsal abdominal artery; 31, sternal artery; 32, ventral thoracic-abdominal artery; 33, supraœsophageal ganglion; 34, subœsophageal ganglion; 35, first thoracic ganglion; 36, abdominal muscle; 37, right spermary; 38, right sperm-duct; 39, opening of sperm-duct end of the carapace there is a prominent beak, or *rostrum* (Fig. 67, 3), beneath which, on either side, extends an *eye* (Fig. 67, 4), borne on a stalk. Study of the living crayfish enables one to see how well the rostrum protects the stalked movable eye. The eye is compound; the manner in which the image is formed is practically the same as in the insects. Crayfishes have no simple eyes.

The cephalothorax bears at its anterior end six slender, many-jointed feelers, the short ones called *antennules* (Fig. 67, 5), the long ones, *antennæ* (Fig. 67, 6). The four antennules are really the two branches of a single pair of appendages coming from a short stem which is attached to the body. On the upper surface of one of the segments of this stem is a small hole surrounded by a number of bristles. The hole opens into a cavity which contains several small grains of sand placed there by the crayfish itself after every molt. (The process of molting is explained in Chapter XIII.) This organ, with its nerve-connections, constitutes the "ear" of the crayfish (Fig. 67, 7), the chief function of which is to help the animal to balance itself during locomotion. The technical name *otocyst* is given to it. The antennæ are the inner branch of a pair of double-branched appendages, of which the outer branch is short, flat, and triangular, and lies just below the eyes, where it serves a protective function. It is called the *squame*. On the lower, or basal, segment of the stem of this pair of appendages is a small, hard, round swelling, or *papilla* (Fig. 67, 8; Fig. 68, II, 1), on which is the opening from the "kidney," or green-gland, shown in broken outline in Fig. 67.

About the mouth are six pairs of appendages. The first, the hard *mandibles* (Fig. 67, 9), are adapted to crushing into smaller bits the food seized by the large claws. Each mandible bears a short *palpus* (Fig. 68, III, 2). Next in the series are the *first* and *second maxillæ* (Fig. 68, IV, V) and the *first*, *second*, and *third maxillipeds* (Fig. 68, VI, VII, VIII). The maxillipeds help to hold the food in place at the mouth; the maxillæ also assist in this, and probably, with the upper and lower lip and the wall of the mouth-cavity, are the seat of the sense of taste. The second pair of maxillæ also act as "gill-bailers" (Fig. 68, V, 3–4; Fig. 69, 1), which, by their motion, help to maintain a current of water in the *gill-chamber* (Fig. 69, 5), thus providing oxygen for respiration. In the maxillipeds a basal stem, with two branches arising from it, can be easily distinguished. The separation between head and thorax is understood to come between the second maxillæ and the first maxillipeds, thus making five pairs of appendages in the head-region.

After the maxillipeds the next thoracic appendages are the large claws, or *chelipeds* (Fig. 67, 11), composed of seven segments, of which the last two from the body, or distal two, are adjusted to form a nipper, with which the animal captures and holds even rapidly swimming fishes. The remaining thoracic appendages are the four pairs of *walking-legs* (Fig. 67, 12; Fig. 68, XI, XII), also composed of seven segments, the first two pairs with nippers at their ends, and the last two pairs without nippers. The three pairs of maxillipeds, the one pair of chelipeds, and the four pairs of walking-legs constitute the eight pairs of appendages of the thorax.

The Abdomen. There are six pairs of appendages on the abdomen. The first abdominal appendages of the female are small, single, and thread-like; in the male (Fig. 67, 13), they are long and rigid, differing considerably from all the others except the second pair (Fig. 67, 14). The second abdominal appendage in the female is like the third. The third, fourth, and fifth pairs, called *swimmerets* (Fig. 67, 15), are alike in both sexes. The pair of appendages of the sixth somite (Fig. 67, 16) are made up of broad flat branches jointed to a short thick stem, and form, with the last somite, called the *telson* (which is without appendages), a strong tail-fin.

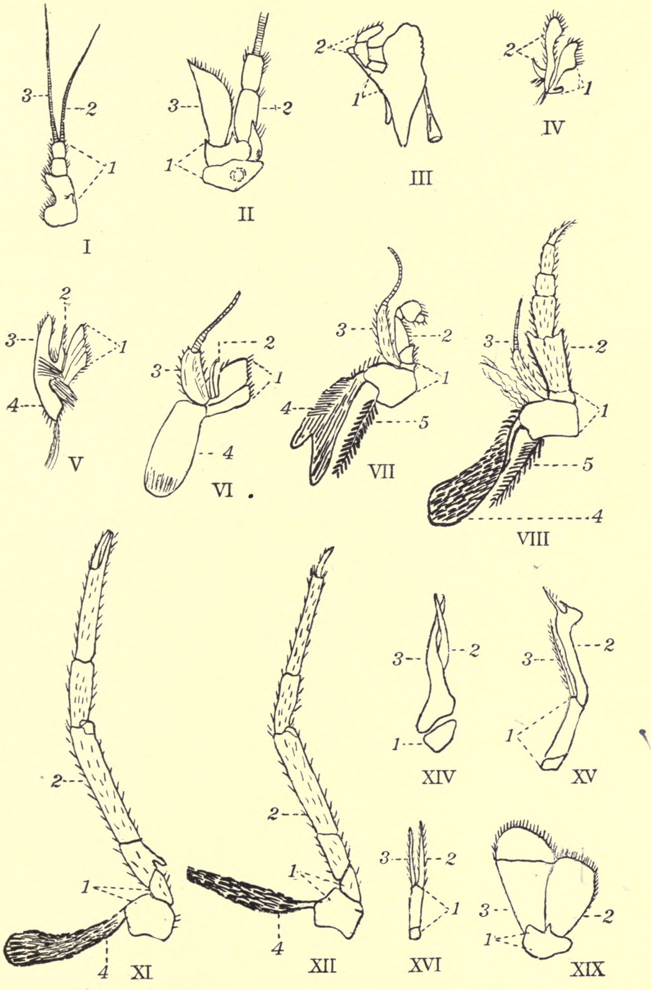


Fig. 68. Appendages of the Crayfish (*Cambarus affinis*), from the left side. Natural size.

(I, II, III, etc., stand for the number of the somite in the animal's body)

1, protopodite; 2, endopodite; 3, exopodite; 4, epipodite with gill-filaments; 5, gill with gill-filaments

By doubling underneath it is capable of striking hard blows against the water and forcing the crayfish suddenly backward. A basal stem with two branches is to be clearly seen in all the abdominal appendages except the first pair in the female.

Homology and Analogy. The fact that a stem and two branches are apparent in several appendages which have been mentioned, is important enough to deserve further discussion. The simplest condition of the branched appendage is seen in the third, fourth, and fifth abdominal appendages (Fig. 68, XVI). If the branches are spread slightly, the form resembles the capital letter Y. Taking a swimmeret as a model, the stem, which is termed the *protopodite* (Fig. 68, XVI, 1), is seen to be made up of a short basal segment, the *coxopodite*, and a long segment, the *basipodite*. Of the two branches, the one nearest the median line of the body is the *endopodite* (Fig. 68, XVI, 2); the outer is the *exopodite* (Fig. 68, XVI, 3). Wherever in the series of appendages we find a stem and two branches, the protopodite corresponds to the protopodite of all the other appendages of the series, — and so with the endopodites and the exopodites.

The legs seem to be formed on a different plan, but we know from the embryology (the science of the early stages of development) of the crayfish that while the egg is still unhatched the embryo has legs that have two branches (compare larval lobster, Fig. 70), and that the outer and smaller one disappears before the embryo hatches. The first and second maxillæ have the parts of a typical crayfish appendage, divided as shown in Fig. 68, IV, V. The crushing part of the mandible is thought to represent the coxopodite and basipodite combined. The little palpus is the endopodite; the exopodite is missing in the adult.

In this brief description of the appendages of the crayfish two very important facts in morphology (the science of form) have been suggested. One, the inherent similarity of structure of the parts of the appendages in a series; the other, a divergence in the forms of appendages because of adaptations to different uses. Perhaps no fact in nature is better known than the fact that organs are adapted in general form and in special parts to perform particular functions. It is only when we come to examine a series of organs like the appendages of the crayfish that we obtain some insight into the very great changes which must often take place before organs become adapted to the performance of even slightly different functions. Morphologists, realizing the extent of the principle of adaptation, have been able to show that in a series of organs, like the appendages of the crayfish, any part of an appendage, as, for example, the endopodite, can be shown to correspond to the endopodite in all the other appendages, no matter what the superficial differences may be.

In referring to these corresponding parts we use the technical term "homologous parts." The protopodites of all the appendages are structurally similar; that is to say, they are situated in the same relation to adjacent parts all through the series. Likewise the legs and the antennæ, being inner branches (endopodites), and being jointed to the second segment of the appendages, are homologous parts. If such unlike parts as the antennæ and the legs are homologous, it is, of course, very clear that the legs and the chelipeds are homologous as whole endopodites, and also segment by segment from the base to the tip. The crayfish appendages are examples of *serial* homology; in a broader sense, homology deals with organs of all sorts that have a corresponding position and origin in different animals. In connection with the study of homology, the science of structurally similar parts, we find the word "analogy" in frequent use. The difference between homologous parts and analogous parts is one easily made clear by applying the terms to the present study. The legs of crayfishes are analogous parts, because their *use* is the same; they are homologous parts because they are *structurally* similar. The same is true, to take another case, of the swimmerets of the third, fourth, and fifth abdominal somites; but whereas the antenna and the legs are homologous, they are not analogous, because their functions are different. Ordinarily, zoölogists use the word "analogous" in a little different way from that suggested above. Instead of being applied to structures in the same animal, it is most commonly applied to organs of similar function in different animals; for example, the wings of insects and birds, — organs which have the same use but are not homologous.

The Digestive System. The *mouth* (Fig. 67, 17) of the crayfish is located between the two mandibles. Reference to Fig. 67, 18, will give an idea of the length of the *œsophagus* and the position and relative size of the *stomach* (Fig. 67, 19). The latter has two more or less clearly marked regions, — the anterior enlarged region and the posterior funnel-shaped space. As the food passes into the anterior portion the unbroken bits are caught between the contiguous grinding surfaces of three hard processes (Fig. 67, 20) extending from the stomach-wall. These three "teeth" — one in the median dorsal line and two at the sides — together constitute the "gastric mill." Muscles attached to them and to the inner surface of the carapace, by contracting, perform the operation of grinding. The posterior part of the stomach is filled with slender filaments which extend from the wall out into the cavity (Fig. 67, 21). These filaments prevent the unbroken particles of food from passing through into the intestine, allowing only the thoroughly ground-up food to do so. Absorption does not occur in either division of the stomach, but in the *intestine* (Fig. 67, 24), which extends straight from the stomach to the ventral surface of the telson. A pair of *digestive glands* (Fig. 67, 23) lie one on either side of the stomach and intestine. They open by tubes into the posterior division of the stomach, and have the combined functions of digesting food and absorbing some of the products of digestion.

The Circulatory, Respiratory, and Excretory Systems. The *heart* (Fig. 67, 26) is a muscular organ lying beneath the dorsal body-wall posterior to the stomach. The blood finds its way into the heart through three pairs of openings furnished with valves to prevent the escape of blood. When the heart contracts the blood flows both forward and backward at the

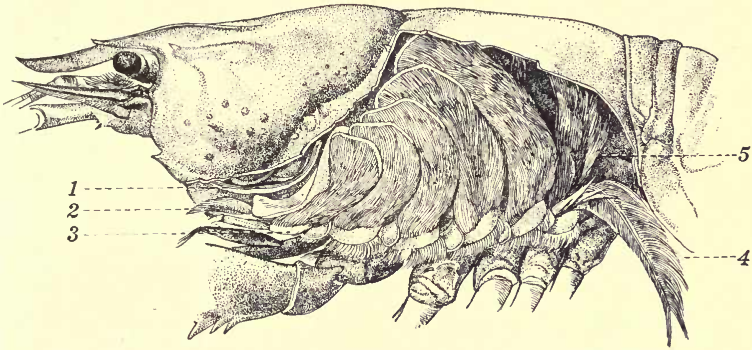


FIG. 69. Gill-Chamber and Gills of the Crayfish (*Cambarus affinis*). Slightly enlarged

1, gill-bailer on second maxilla; 2, first maxilliped; 3, second maxilliped with first outer gill; 4, sixth outer gill; 5, last gill of inner series

same time, forward by five tubes and backward by two tubes, called *arteries* (Fig. 67, 29, 30, 31). These arteries branch into many smaller vessels with open ends; from the open ends the blood flows over the tissues of the body in *sinuses*, all of which connect with a still larger median cavity, the *ventral sinus*, lying along the ventral wall of the thorax and abdomen. Branches from the median ventral sinus extend out into the gills. The blood is carried back to the base of the gills by parallel channels, and finally carried up to the *pericardial sinus* in which the heart lies. The set of delicate, plume-like *gills* (Fig. 69, 4) are attached to and near the basal joints of the thoracic appendages, and extend dorsally into partially closed chambers bounded by the body-wall on the inside and the ventral extension of the carapace on the outside. Since it is sometimes necessary for the crayfish to make journeys from pond to pond in dry seasons, the gills are thus protected from sudden drying. Water is drawn into and out of this gill-cavity by means of the action of the gill-bailers on the second maxillæ already referred to (Fig. 68, V, 3–4; Fig. 69, 1). The blood flowing into the gills from the ventral sinus gives up its carbon dioxide waste and receives oxygen from the water.

The *green-glands* are prominent organs (Fig. 67, 8) in the ventral region of the body-cavity in the head. A large artery carries blood to them, and nitrogenous waste matter is separated by them from the blood and finds its way to the opening on the basal segment of the antennæ.

The Nervous and Muscular Systems. The "brain," the *supraœsophageal ganglion*, of the crayfish is a mass of nervous tissue resulting from the aggregation of several pairs of ganglia (Fig. 67, 33). Pairs of *nerves* may be traced to the eyes, the antennæ, and the antennules. Two slender connectives, similar to those described for the locust, extend from the brain, encircle the œsophagus, and join the *subœsophageal ganglion* (Fig. 67, 34) posterior to the mouth. This ganglion, too, is really a combination of several pairs of ganglia, which send off the nerves to some of the head somites and to some of the thoracic somites. There are five other ganglia in the thorax joined to each other (first thoracic ganglion, Fig. 67, 35), and to the six ganglia in the abdomen, by the double nerve-cord which is a continuation of the connectives that encircle the œsophagus.

The *muscles* of the abdomen are arranged in a very complicated fashion and are capable of powerful action. In all parts of the body muscles are attached to the inner surface of the exoskeleton.

The Reproductive System. The male reproductive organ, the *spermary* (Fig. 67, 37), and the female reproductive organ, the *ovary*, lie just below the heart; each consists of a three-lobed organ. In the male a *sperm-duct* (Fig. 67, 38) leads from either side of the spermary to an opening (Fig. 67, 39) on the basal segment of either fourth walking-leg. In the female the *oviducts* lead to similar openings on the second walking-leg.

Development. Cambarus affinis lays its eggs in the spring. Most species of crayfishes lay their eggs then. The principal burrowing species, *Cambarus diog'enes*, lays its eggs in April and they hatch in May, while a river species, *Cambarus immu'nis*, lays its eggs in the fall and they hatch in the following spring. When the egg-laying season arrives the male deposits spermatozoa in a shallow cup called the *annulus*, on the ventral surface of the female, between the fourth pair of legs. The mass of spermatozoa stays in the annulus till the female lays her eggs. It is not certain how long the spermatozoa lie there before the eggs are laid. However, when the eggs are discharged from the oviduct they pass back over the mass of spermatozoa. Fertilization is accomplished when a spermatozoön enters an egg. The fertilized eggs are carried back and fastened to the swimmerets by a glutinous substance. There the embryos develop, and the larvæ, when they hatch, remain clinging to the female's swimmerets by their chelipeds for some time, probably several weeks.

Relation to Environment. Crayfishes live in a great variety of places. They are fresh-water animals, but one species has also been found in the sea. As a rule, they crawl on the bottom of rivers, brooks, and ponds, concealing themselves in crevices or under protecting pieces of rock or submerged logs. Several species make burrows in the soft earth of meadows. The most widely distributed of these is Cambarus diogenes. Species which live in ponds that are likely to dry up in the summer, and also a few that live in rivers, leave the water in summer and burrow into the earth until they come to water. At the bottom of their burrows, sometimes three feet from the surface, they dig out a flask-shaped enlargement and stay in it or near it till the next spring. The chimneys made at the top of the "wells," referred to in the quotation at the beginning of the chapter, are made by the burrowing crayfish merely as an incident in getting rid of the mud brought from below. Sometimes crayfishes stop up their burrows completely. In that case they probably remain in a dormant condition without food till spring returns. In the bed of a pond or river where jutting stones abound crayfishes rest with the abdomen doubled beneath them and the head toward the open. Boys often lure them from their hiding-places with a piece of meat tied to the end of a weighted string. The animal invariably seizes the meat in a cheliped, and usually can be drawn to the surface before it has time to "think" the matter over and let go.

The distribution of crayfishes is directly related to their power of adapting themselves to conditions of considerable variability. If a certain definite degree of temperature or of clearness of water were required, they would be restricted to a very limited area, and, indeed, it would be difficult for them to maintain themselves at all. As it is, we find them in drinkable water, in muddy water, in sulphur-laden water, and in sea-water, but never in the water of streams or ponds of a country devoid of limestone. This accounts for their absence from the eastern part of New England, where the rocks are largely of granite.

A striking example of adaptation to an unusual environment is found in the cave-dwelling crayfish, *Cambarus pellu'cidus.* Professor Eigenmann of Indiana, Dr. O. P. Hay of New York, and others have explored the caves of Indiana and Kentucky for the purpose of studying the animals of their subterranean rivers. The blind crayfish has small and abortive eyes, but its sense of touch is developed to a marvelous degree of delicacy. Dr. Hay says that although the crayfishes may be resting quietly on the bottom of a rivulet, it is impossible to capture them with a net. They feel the jar in the water and dart backward with great accuracy to a protecting rock. In general appearance the blind crayfish differs from others chiefly in having an exoskeleton which is so clear that one may see the animal's stomach as a blue mass within, and in being provided with antennæ longer than the body.

Crayfishes are eaten by fish large enough to swallow them, and they in turn catch small fish with great facility, and also insect larvæ, snails, tadpoles, and even frogs. They have been known to prey upon each other, and also to eat dead organic matter; but as a rule they eat plant and animal food in the fresh condition.

They are protected by their hard shells from the attacks of passing fish. The color of the shell is more effective still, since whatever the color of the bottom, it is closely imitated in the distribution of color pigment in the shell. The usual color is muddy greenish-black; in ponds where the mud is bluish, the shell is also blue. An account has been written of the crayfishes found in Sandy Lake, Pennsylvania, where the bottom is white marl and clay. All the crayfishes which have been captured in the pond "vary in color from almost pure white to pink, or in some cases to a delicate greenish tint. They are practically invisible when at rest. The fishermen of the district capture them and use them for bait to catch bass in other lakes where the bottom is of dark mud."

In America crayfishes seem to be used as food chiefly by the French portion of our population. Possibly the rapid depletion of the lobster fisheries may cause people generally to turn to the lobster's nearest edible relative. In France the crayfish industry is quite extensive, there being many farms on which crayfishes are raised for the market.

CHAPTER XIII

THE JOINTED-FOOT ANIMALS: ARTHROPODA

The Shelly Crawlers each returning year
Cast off their shells and new-made Armour wear.

OPPIAN, *Halieutica.*

THE ALLIES OF THE CRAYFISH: CRUSTACEA

The Lobster. Except for the considerable difference in size, and the slight differences in the shape of the body, the number of gills, and the structure of abdominal appendages, the description of the adult crayfish would serve for an account of the structure of our common species of American lobster, *Hom'arus america'nus.* The lobster is found in greatest numbers along the coast of Maine and the Canadian maritime provinces. Toward the south the number gradually decreases to the Delaware breakwater, beyond which they are very rare. In their days of greatest abundance they grew to be about sixty centimeters (two feet) in length, weighing twenty-five pounds, but with the increase in the activity of the lobster-fishing industry they are now rarely to be found weighing over two pounds.

The lobster lives on the bottom. It is protectively colored, but it does not depend wholly upon that condition for escaping the notice of its enemies. In shallow waters lobsters are known to conceal themselves beneath masses of brown seaweed in pits and holes, and also to find safe retreat beneath jutting ledges of rock, where they rest with the abdomen doubled beneath, ready to dart out and seize passing prey in their claws. We have no way of knowing the exact habits of the animal when at its greatest depth (a hundred fathoms), but since its enemies are probably quite as persistent there as in the shallow water, every means of defense is likely to be employed to the utmost.

The lobster is capable of swimming with great rapidity, by suddenly doubling its flexible, muscular abdomen beneath and shooting backward through the water. The habit does not appear to be depended on except to enable them to escape from impending danger. Their usual mode of progression is by walking on the tips of the last four pairs of thoracic appendages, the chelipeds being extended anteriorly, apparently to expose as little of their bulk to the water as possible. The swimmerets waving in rhythmic motion aid the animal in its movement along the sea-bottom.

With all their appearance of armored strength, lobsters are very sensitive to changed conditions in their environment. When captured and detained in "pounds" (artificially inclosed spaces), in shallow water, they will, on the approach of winter, dig burrows in the sea-bottom and cover themselves all but their eyes and antennæ. There they remain in a dormant condition until the returning warmth of spring affects the temperature of the water. In their natural environment they migrate to the deep waters in the autumn months and remain there till spring. We know that they do not make burrows and lie inactive in the deep waters, because fishermen catch them in baited traps in all the winter months. In the winter in our latitude deep waters are warmer than shallow waters; in summer the shallow waters are warmer. Lobsters are sensitive to even slight changes in temperature. In the early summer they have been known to return to deep water immediately on the occurrence of a storm in the atmosphere above them. Another factor which must operate strongly in determining the migration to the shore is the greater supply of food there. Lobsters do not appear to migrate up and down the coast. Hence, if all the lobsters in a certain bay and vicinity are caught, the chances are against that region recovering its lost supply.

Slow, inactive animals living on the bottom fall an easy prey to lobsters. When confined in pounds, lobsters even dig up clams and crush the shells in their powerful crushing claw, which is the thicker one of the two. Fish also are caught, even where both captor and prey have perfect freedom of action. Those who have studied the habits of lobsters closely believe that although the lobster is a scavenger in the sea, it nevertheless prefers living food to dead organic matter. Seaweeds form part of their food. The processes of eating, swallowing, grinding in the stomach, and digestion are exactly the same as in the crayfish.

Molting in the lobster, as in some other animals with a hard exoskeleton, is an extremely important and critical event, since the store of vitality is drawn upon in preparation for the act of shedding the hard armor, and in fully restoring a protective sheath. In the act of molting, the lobster does not, as a rule, split the dorsal shell. The animal bends, making a sharp angle at the junction of the cephalothorax and the abdomen. The soft body at that point begins to withdraw from the carapace. Getting out of the rigid shell is made possible by a preliminary process of taking up into the blood the lime in the exoskeleton, along the median line of the carapace, at the rostrum or beak, and at the narrow joints of the cheliped and walking-appendages. The blood leaves the appendages and flows into the sinuses of the cephalothorax. The withdrawal of the cephalothorax and its appendages soon follows, and lastly the abdomen is withdrawn from its old covering, and the soft, defenseless lobster conceals itself as quickly as its weakened condition will permit. The volume and weight rapidly become greater, due to the absorption of water. Later, while the new shell formed beforehand under the old one is becoming harder, the water previously absorbed is replaced by true tissue. This periodic growth of the lobster really begins before the act of molting takes place; in fact, the physiological need for more room is what brings about the act of getting rid of the old exoskeleton. The number of molts an individual lobster may have depends, in a great measure, upon the abundance of its food. Males molt more frequently than females; hence the largest lobsters are always males. Very young lobsters molt more frequently than those of the size we find in the market. During the process of molting it sometimes happens that an appendage is broken off. In the ordinary course of its life, also, the lobster may lose a claw or an antenna. It is regenerated in two or three molts after the accident. The crayfish and many other animals closely related to these two have the same power.

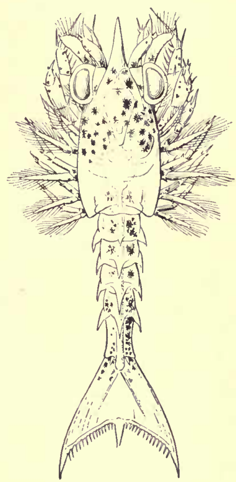


Fig. 70. First Larval Stage of American Lobster. × 7. (After Herrick)

The female lobster lays her eggs usually during the summer months. The eggs remain attached to the swimmerets until the next spring, when the embryos hatch. The larval lobster (Fig. 70) immediately floats to the surface, and for several weeks swims about there. Its length at first is about eight millimeters (one third of an inch). In general appearance it resembles the adult lobster, except that the large thoracic appendages are two-branched and the abdomen has no appendages. After the sixth molt the lobster, then about two thirds of an inch long, has lost the outer branches of the legs, has gained abdominal appendages, and is nearly like the adult in other respects. At about this time the young lobster leaves the surface, goes to the bottom, and makes its way to well-protected places near the shore.

The commercial value of the lobster is very great. As an article of human food it is fast becoming a luxury. Considering its original abundance at times when a fifteen-pound lobster could be bought at the fisheries as cheaply as a two-pound lobster, that is, for two cents, we may well ask whether it is not time for the ratification of treaties between the United States and Canada to govern more effectively the activities of persons engaged in supplying the market. The researches of Professor Bumpus, Professor Herrick, and others, have made it clear that a female lobster seldom lays eggs before she is at least eight or nine inches long. Although she carries about five thousand eggs the first time, two years later she would lay many thousand more than that number. Because of the numberless enemies the young encounter, few live to adult life from these thousands of eggs. Legislation which permits lobsters to be caught before they are eight inches long may ultimately be responsible for the extermination of the species. Sensible laws and increased facilities for hatching lobsters in captivity and releasing them after the first critical stages, would do much toward replenishing the lobster fisheries.

The Common Prawn. Small animals which live at or near the surface of the water are, if brightly colored, so small that they are invisible ; if of visible size, they incline toward transparency. The familiar prawn (*Palæmone'tes vulga'ris*, frontispiece), found abundantly among seaweeds near shore in sea water and also in brackish and almost fresh water, is a good example of a pelagic or surface-inhabiting animal of considerable size, which is so nearly transparent that it may be overlooked unless it moves. The prawn, or, as it is frequently called, the shrimp, is about two inches long and resembles in general form the lobster or the crayfish. The body is, however, more compressed (flattened from side to side), and more strongly arched from head to tail. The carapace is thin but tough and leathery, and covered with many reddish-brown dots; it is so transparent that the stomach and intestine can be seen clearly while the animal is at rest.

The appendages show some interesting adaptations. The antennæ are as long as the body, very slender, and during forward locomotion are constantly waving through the water. One of the antennules on either side extends forward, and the other backward, over the eye. At times, in sea-water aquaria, the recurved antennule appears to be clearing the surface of the eye of dirt. The cheliped is only about two thirds as long as the first walking-leg; it has the curious habit of bending backward frequently at a middle joint like a knee. The first walking-leg also has a nipper, and is much used for grasping food. The remaining three appendages of the thorax are about the length of the cheliped, and end in a single point. When at rest the prawn is usually found clinging easily to the under surface of seaweeds.

Crabs. The species represented in Fig. 71 (*Eupagu'rus pollica'ris*) is called the hermit-crab, probably because it lives in a "house" by itself. The house consists of the shell of a dead snail which may have been washed to the beach, or may have rested on the bottom of the bay. The hermit-crab in its early life is pelagic, but at a certain stage of its development it sinks to the bottom, finds a snail-shell, and backs into it; from that time on, the general shape of the body and the special modification of certain organs are determined by the form of the snail-shell. The abdomen is soft, and all the abdominal appendages except the terminal ones are misshapen and useless. The terminal appendages extend laterally like flanges, and prevent the body from being drawn forcibly from the snail-shell by an enemy. The chelipeds are abnormally developed and, besides being of use in capturing prey, serve the important function of closing the aperture of the shell in times of danger.

Hermit-crabs live in great abundance along gravelly beaches, where they are useful scavengers of dead animals in the water. In spite of the heavy houses which they carry, they move about with surprising facility. As suggested by one observer, they are wary, cunning, belligerent, and cowardly, making great pretense of fighting, but on the first show of force by an opponent they withdraw into their shells.

A small shore species more frequently seen never becomes as large as Eupagurus pollicaris, which is a deep-water species. All the species, however, when the individuals are young,

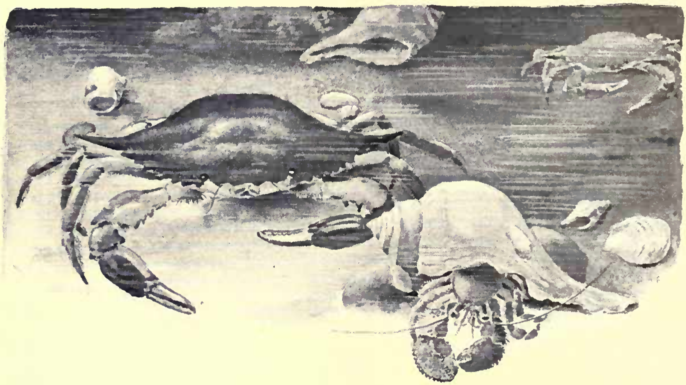


Fig. 71. Hermit-Crab and Blue Crab. × $\frac{1}{4}$

choose small shells; as they grow older and larger after each molt, the unused space in the shell becomes less and less. Naturalists have observed the action of hermit-crabs that have become too large for the shell. The animal searches about for a suitable larger shell, and when it finds one withdraws the body from the old shell and extends it into the new.

The spider-crab (*Libin'ia emargina'ta*, frontispiece) stalks slowly over the sea-bottom in shallow and deep water where rocks and fixed plants and animals abound. It can neither run nor swim, an inference which might be drawn from the slender, stilt-like appearance of its legs. Having no means of aggressive defense, it relies almost wholly on the fact that its color is very much like its surroundings. The cephalothorax is covered with coarse, hair-like, flexible spines, and the general color is dull gray. Frequently we find on the back small seaweeds, hydroids (p. 265), sea-anemones (p. 252), and even rock-barnacles (p. 151), growing as they would on rock. This protective resemblance appears to be very successful from the point of view of the spider-crab, for they are in some regions more abundant than any other kind of crab. In some parts of Long Island Sound the spider-crabs are so numerous that they get into the "lobster-pots" set by fishermen and crowd them so that no inducement remains for the lobsters to enter, much to the disgust of the fishermen. Along the Atlantic coast this species grows to have chelipeds which extend over one foot from tip to tip. The giant Japanese spider-crab has chelipeds which extend over fifteen feet from tip to tip, and has a body correspondingly large.

The edible crab, more frequently called by naturalists the blue crab (*Callinec'tes sap'idus*, Fig. 71), is characterized by having sharp lateral spines of large size, and by the last pair of thoracic appendages being flattened and adapted to swimming. The chelipeds are strong and fitted for cutting; the succeeding three pairs of appendages have no nippers, but come to a point.

As is well known, the blue crab is caught in large numbers along the Atlantic and Gulf coasts for the markets in the cities. The industry is of considerable value commercially, and for that reason very general attention has been given to the distribution and habits of this crab. They are caught most easily soon after the molting, which takes place in early summer, and are then called soft-shell crabs. It is at this time also that they are considered most valuable as food.

The blue crab is not confined to the salt water, for it is found frequently in rivers some distance from bays. Wherever they are, they devour much of the organic waste that is carried down to the sea. They are therefore important as scavengers.

The most noticeable feature in the structure of the fiddler-crab (*U'ca pugila'tor*, Fig. 72) is the presence in the males of a large cheliped. Sometimes it is the right one that is larger, and sometimes the left one; the females have their chelipeds small and of equal size. The name "fiddler" is supposed to have been derived from the fancied resemblance of the large cheliped to a fiddle, and of the small one to a bow.

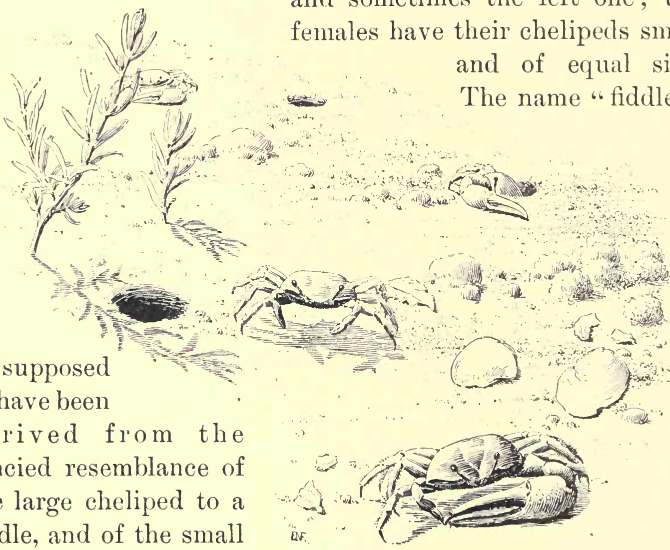


Fig. 72. Fiddler-Crab. Slightly reduced

Fiddler-crabs live in the mud and sand of salt-marshes along the Atlantic coast. Sometimes on the higher ground where the sand is cleaner and drier, and where vegetation is scant, these crabs may be observed by the cautious visitor, as they glide quietly out of their holes bearing pellets of sand and gravel under their legs and cephalothorax, to deposit the burden a foot or more away from their holes. The species shown in the picture has been observed to carry on this process of excavation in the brightest sunshine and at night. In feeding it seems to prefer plants, living upon very small green algæ which grow on the moist sand. The male picks up these algæ with its small cheliped and passes them to its mouth, or collects them in pellets to carry into its hole in the same way that it carries pellets of sand out of it.

The Sow-Bug. The sow-bug, and a related species called the pill-bug because of its habit of rolling up into a ball, are found under stones, boards, logs, and in other dark, moist places. They live on vegetable matter. The flattened condition of the body reminds one of the cockroach and the cricket, which show the same adjustment of the form of the body to the necessities of their life. The species represented (Fig. 73) belongs to the genus *Onis'cus.*

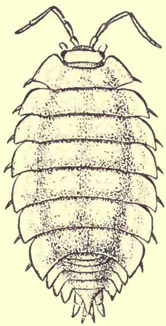


FIG. 73. Sow-Bug. × 3

The body has twenty somites, as have the crayfish and all the forms described so far in this chapter; five of these, with one thoracic somite, are fused in the head-region; seven thoracic somites are free-moving, and of the seven abdominal somites all are free-moving except the last two. A pair of short, jointed antennæ and a pair of compound eyes without stalks, i.e. *sessile* eyes (Lat. *sedere*, to sit), are the most noticeable organs of the head. They have a second pair of antennæ, which are rudimentary. The mouth-parts are small and adapted to feeding on plant-food. The breathing organs are gills, protected by flat, plate-like structures on the under surface of the abdomen. The base of the legs of the female bears other small plates, which, with the under surface of the body, form a brood-pouch in which the eggs are carried and the young developed.

Caprella. Probably one of the strangest looking free forms to be found in the sea is the little brown *Caprel'la* *geomet'rica* (Fig. 74). Unless one should see it represented in its natural environment, or actually find it there, the peculiar slender form and the widely separated groups of legs could not be explained on the ground of adaptation to its environment. The artist has shown the details of structure, and also the general resemblance of the body and appendages to a portion of the brown seaweed. The animal is a little over a centimeter long. The four flap-like appendages in the middle regions are gills. Caprella is composed of twenty somites.

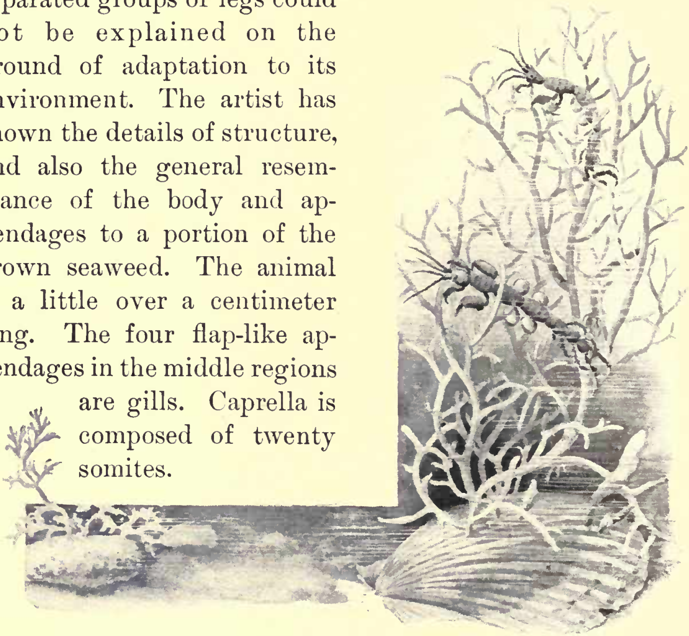


Fig. 74. Caprella. × 2

Artemia. The genus *Arte'mia* is found in brackish water (see larva, Fig. 78, p. 152). It is particularly interesting in the light of experiments showing the direct influence of the environment on an animal form. From 1871 to 1874 the Russian naturalist Schmankewitsch experimented with Artemia. In one series of experiments he increased the density of the brackish water in which they lived by adding salt; in another series he diluted the brackish water by adding fresh water. After several generations of Artemia had been produced under these conditions it was found that the individuals in the water to which salt had been added were of the form of a species hitherto supposed to be distinct, and bearing a different specific name. The individuals in the water which had been gradually diluted approached the form of an allied genus. Thus a mere change of the amount of salt in solution seems to have been responsible for the different forms assumed by the descendants of the same race.

Cyclops. Any fresh-water pond will afford millions of the genus *Cy'clops* (Fig. 75), and the sea contains species of the same genus in such numbers that they with allied genera form a large part of the food of many fishes, and even some species of whales find in them an abundant food-supply. Their powers of reproduction are so enormous that it has been estimated that the descendants of one Cyclops may number, in one year, 4,500,000,000 individuals. Though microscopic in detailed structure, on close observation it is easy to see them darting spasmodically through the water in aquaria. A single compound eye in the middle of the head gives them their name, in reference to the race of mythical giants of Sicily. Two pairs of antennæ, used in locomotion, extend from the front of the head. The legs are two-branched appendages, also used in swimming. One pair of antennæ and the legs are not shown in the figure. Two long appendages extend from the end of the abdomen. The body consists of fifteen somites, five in each of the three regions, head, thorax, and abdomen. The female, in the summer season, carries about with her two large brood-sacs of eggs which extend diagonally out behind.

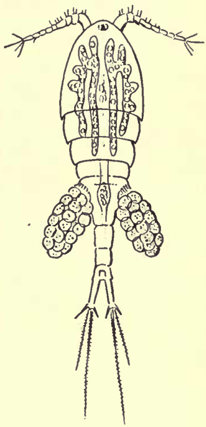


Fig. 75. Cyclops. Much enlarged. (After Claus)

Parasites. A large number of different forms resembling Cyclops in many respects have adopted a parasitic life. One of them is shown in Fig. 76 (*Lernæoc′era*). They occur on various hosts, but the greater number of them are found on fishes. They live on every part of the body, and in every degree of commensalism and parasitism. Some live in the alimentary canal, or in the gill-region, feeding only on the food of the host; some temporarily seek their host for the body-fluids, while others are permanent parasites, external or internal. In general, these forms are spoken of as "fish-lice." To the extent that they are dependent on a host, the normal external structure tends to be modified out of all resemblance to the type represented by Cyclops. The somites lose their distinctness, and the form of the body is altered by protuberances of various kinds. The mouth-parts become adapted as holding and sucking organs. As the external organs degenerate, the tendency of certain internal organs is also to become rudimentary. Some of these parasitic organisms are so degenerate in form and structure that they have lost all appearance of being animals at all. In many cases it is the female only which is parasitic, the males leading a free life and showing the normal structure of their race. As with most parasites, immense numbers of eggs are produced, to overcome the effect of the somewhat isolated positions they occupy. Lernæocera is parasitic on the carp, a fish. The form is considerably modified, but the egg-sacs signify its relation to Cyclops.

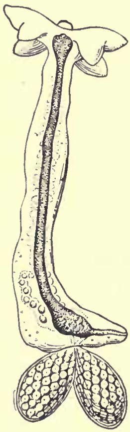


Fig. 76. Parasitic Crustacean. Much enlarged. (After Von Nordmann)

Barnacles. Despite the great apparent difference between the fixed, shell-bearing barnacles (Fig. 77) and the free-swimming crabs and other forms discussed in this chapter, naturalists have shown that they are in reality closely allied both in development and in structure. The species shown in the accompanying figure is the rock-barnacle (*Bal'anus balanoi'des*), the most common barnacle along the North Atlantic coast. In some places it literally incrusts the coast-rock between tide lines with its hard, sharp-edged shell, composed of carbonate of lime. The shell is usually a little over a centimeter high, and narrower at the top than at the base. Related species grow to be at least four centimeters high, and

FIG. 77. Rock-Barnacle. Reduced

one is found on the back of whales. At the top of the rock-barnacle are two hard, movable valves, meeting in a median line, which, on opening, expose long, feather-like processes. These processes are, morphologically, divisions of the feet. The animal lies on its dorsal surface within its several-valved shell, and by rapid movement of the feet creates currents of water which bring to the mouth microscopic animals and plants as food. When the feet are not scooping in food the valves are closed, forming a most effective armor for the parts beneath.

Though the barnacle in its adult condition, as just described, has nothing to fear, in early life the situation is quite different, for it swims free at the surface of the water in the midst of millions of the young of crabs and other animals. There it is subject to the attacks of animals which might devour it, and many young barnacles are undoubtedly destroyed. At this time it would not be recognized as a barnacle by those who have seen only the adult form. It is characterized by having an unsegmented body, a long upper lip, single median eye, as in Cyclops, and three pairs of jointed locomotor appendages. This larval form is called a *nauplius*, and resembles Fig. 78. The barnacle nauplius stage undergoes further complicated changes before it attaches itself by the head to some solid object, as a rock, pile, or ship-bottom, when the swimming appendages are absorbed and the shell and feathery foot-processes are developed.

Definition of Crustacea (Lat. *crusta*, a shell). The crayfish and the species mentioned thus far in this chapter belong to the class *Crusta'cea*. They are constructed on the plan of a series of body-divisions (somites) seldom exceeding twenty in number. In general, the somites are bilaterally symmetrical (uniform in structure on either side the median line). Each somite usually has a pair of branched, jointed appendages. As a rule, two pairs of antennæ are present. A varying number of thoracic somites, in different members of the class, are fused to the head. The exoskeleton contains chitin and carbonate of lime. Crustacea are essentially aquatic in their habits and, with the exception

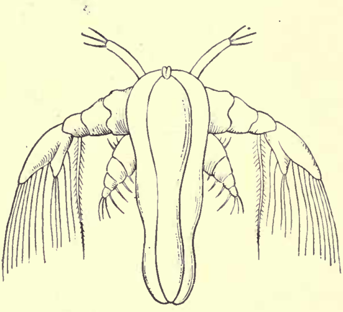


Fig. 78. Nauplius Stage of Artemia. Much enlarged. (After Joly)

of the lowest forms, breathe through gills. Nine tenths of the class are said to live in the ocean, some in fresh water, and relatively few on land.

As in the insects, the hard exoskeleton necessitates frequent molts to provide for growth, and also, as in that class, growth is sometimes accompanied by marked metamorphosis after hatching. The lower forms, such as Cyclops, the barnacles, and the parasitic Crustacea, hatch as the peculiar nauplius type of larva already mentioned in the description of the rock-barnacle and illustrated in Fig. 78.

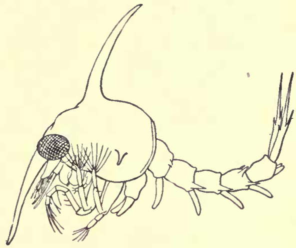


Fig. 79. Zoea Stage of Crab. Much enlarged. (After Emerton)

In the higher Crustacea the crabs pass the nauplius stage in the egg and hatch in the *zoea* stage (Fig. 79). The lobster passes the nauplius and the zoea stage in the egg, and hatches in the *mysis* stage (Fig. 70). The crayfish passes all three stages in the egg, and hatches practically in the form of the adult, the young growing without subsequent metamorphosis. It is important to note that the stages nauplius, zoea, and mysis, in the development of the higher Crustacea, are practically identical with the adult form of certain other Crustacea which are considered to be more primitive in organization. The fact that the lower type form reappears in the development of the higher is often cited as evidence in favor of the recapitulation theory referred to in the chapter on insects.

The Trilobites

Some of the most abundant of the forms in the earlier periods of life on the earth were the *Tri'lobites* (*Pha'cops cauda'tus,* Fig. 80), which are now considered to be closely allied to the Crustacea. They are named trilobite from the apparent division of the body longitudinally into three parts. The length of the body varied from one inch to two feet. They are thought to have lived in shallow waters along shores, and through a long period of the earth's history must have been a most characteristic feature of the fauna of the world. Of the many species of trilobites of which we find fossils, not one remains at the present day.

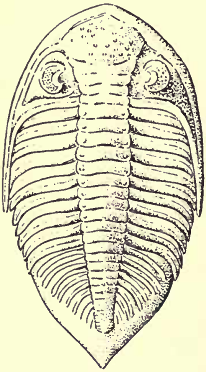


FIG. 80. Trilobite

(From *Report of Geological Survey, United Kingdom*)

THE HORSESHOE CRABS: XIPHOSURA

The large, crab-like animal shown in Fig. 81 is variously known as the horseshoe crab, the king-crab, the horsefoot, and by its scientific name, *Lim'ulus polyphe'mus.* The first and last common names are derived from the shape of the cephalothorax. A pair of simple eyes is placed near the median dorsal line; a pair of large compound eyes is on the sides of the cephalothorax. There are five pairs of legs on the under surface of the cephalothorax. Several pairs of plate-like gills are attached to the under surface of the abdomen. The body is terminated by a long, spear-shaped spine, — which characteristic gives the group its name, *Xiphosu'ra* (Gr. *xiphos*, sword; *oura*, tail).

Limulus is found in sheltered bays and estuaries along our eastern coast from Maine to Florida, and on the coasts of the West Indies and Mexico. In places where it is most abundant it is caught with rakes, killed, dried, and used as a fertilizer. It is also used for baiting eels and other fishes. Its practical extinction is threatened in many places.

The illustration shows the horseshoe crab almost buried beneath the sand through which it is plowing in search of worms. Sometimes they plow a few inches below the surface. The older ones, thirty to forty centimeters in length (twelve to sixteen inches), burrow in deeper water; small ones may often be seen on sand-flats where the water is only a few inches deep. At the time of high tides in May, June, and July, the mature males and females, the latter always the larger, leave the water and make their way up the sandy shore to a point just below high-water mark. The female digs a hole in the sand, deposits her eggs, and the male follows and deposits the "milt," or spermatozoa, over the eggs. Both animals then return to the deeper water, and the retreating tide covers the eggs with sand. The young

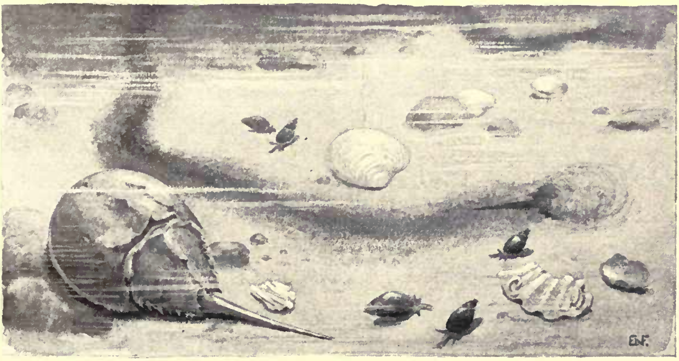


FIG. 81. Horseshoe Crab

hatch in about four or five weeks, and make their way into shallow water. When first hatched they resemble young trilobites in form.

The horseshoe crab is a peculiar type. It shows many points of similarity to both crustaceans and arachnids, particularly the scorpions, and it may be that the latter have descended from these aquatic forms, which are an extremely ancient stock. Some of the fossil allies of the horseshoe crab grew to be five or six feet long.

Definition of Arthropoda

The animals described so far in this book belong to the phylum (see p. 97) *Arthrop'oda* (Gr. *arthron*, joint; *pous* (*pod*), foot). All but a very few members of this phylum are included in the four classes, Hexapoda, Arachnida, Myriapoda, and Crustacea.

The body of an arthropod is made up of bilaterally symmetrical somites arranged in a linear series. There is always a head composed of from four to six fused or united somites. The somites of the remainder of the body are grouped into one region, the trunk (Myriapoda); or into two regions, thorax and abdomen (Hexapoda, some Crustacea). The head is sometimes fused with the thorax, the abdomen being a distinct region (Arachnida, some Crustacea). Appendages, wherever present, are jointed or segmented, and occur as single pairs on somites. The somites and appendages are covered with a chitinous exoskeleton; in some members of the phylum the exoskeleton is very hard and filled with carbonate of lime.

The digestive tract extends nearly straight through the body from the anterior end to the posterior end. The blood, which is colorless, is carried through the body in a partially complete system of vessels with a tubular, or heart-like, pumping organ in the dorsal region of the body-cavity.

Respiration takes place through gills (Crustacea), lung-like sacs (Arachnida), or through an internal network of tubes (tracheæ) opening in two lateral series on the exterior of the body (Myriapoda, Hexapoda, and some Arachnida).

The nervous system generally consists of a "brain," dorsal to the gullet, two connectives passing one on either side of the gullet, and uniting below to form a ganglion, from which a double nerve-cord extends along the ventral body-wall to the posterior end. Sense-organs characteristic of the phylum are segmented tactile organs, and simple and compound eyes.

CHAPTER XIV

THE CLAM AND OTHER BIVALVES: PELECYPODA

And I then engaged myself, with the other merchants, in a pearl fishery in which I employed many divers on my own account.

SINDBAD THE SAILOR, *Arabian Nights.*

THE LONG-NECK CLAM

Habitat and Distribution. The animal which is described first in this chapter is commonly known as the long-neck clam or the soft-shell clam. It is more accurately designated by its scientific name, *My'a arena'ria* (Fig. 82). As the specific name implies, the animal lives in the sand. It is found in great abundance along our Atlantic coast, even as far north as the Arctic regions.

External Structure. The *shell* of the clam has the same general use as the carapace of the crayfish. In both animals these hard external parts protect the organs within from injury, and also afford surface for the attachment of muscles. The clam's shell, however, is never molted. It grows continuously from the time it begins existence, at the little rounded prominence called the *umbo* (pl., umbones), or beak (Fig. 82, 1).

Any one who has examined a dry shell of this kind can tell which is the youngest portion of the shell. Probably he will observe at the same time the little spoon-shaped piece extending horizontally inward from one of the valves of the shell. This projection is always on the left valve. It meets a brown, rubber-like pad beneath the umbo of the right valve, and is joined with it. As long as the two valves hold together at this point, the pad, which is called the hinge-ligament, has a tendency to separate the valves at an acute angle. In life

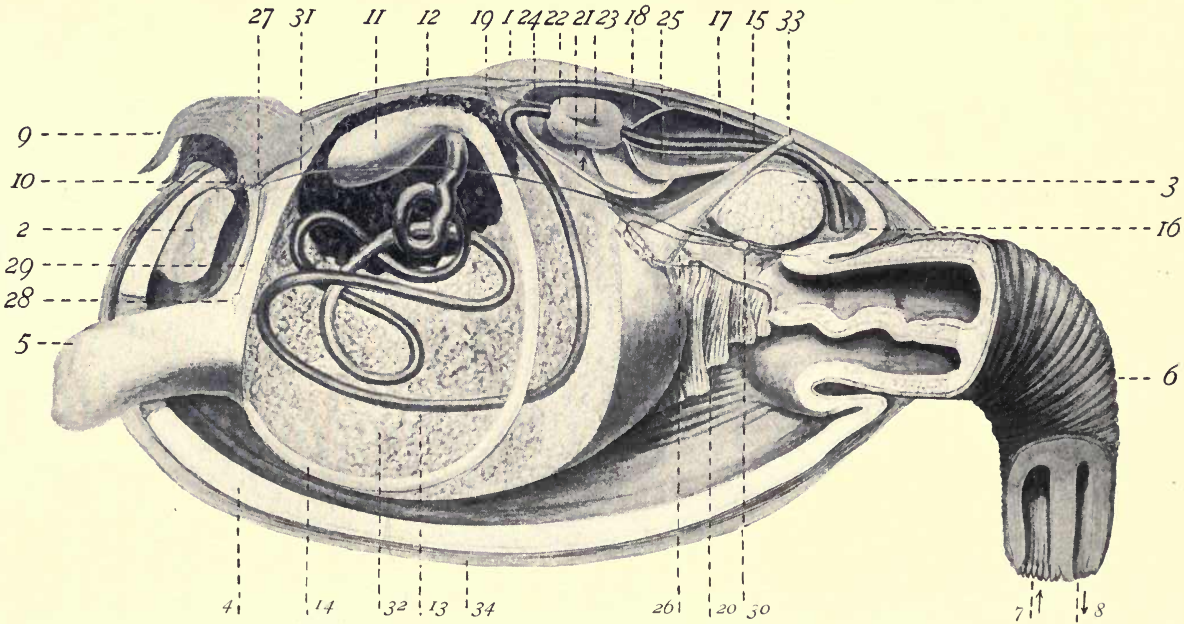


Fig. 82. Dissection of the Soft-Shell Clam (*Mya arenaria*). Natural size

1, umbo, or beak; 2, anterior adductor muscle; 3, posterior adductor muscle; 4, mantle; 5, foot; 6, siphon; 7, incurrent tube of siphon; 8, excurrent tube of siphon; 9, palps; 10, mouth; 11, stomach; 12, digestive gland; 13, intestine; 14, crystalline style; 15, rectum; 16, anus; 17, unknown organ; 18, pericardium; 19, end of nephridium; 20, right inner gill; 21, right auricle; 22, ventricle; 23, valve of ventricle; 24, anterior artery; 25, posterior artery; 26, passage between mantle-cavity and excurrent tube; 27, cerebro-pleural ganglion; 28, pedal ganglion; 29, cerebro-pedal connective; 30, visceral ganglion; 31, cerebro-visceral connective; 32, reproductive glands; 33, posterior retractor muscle; 34, shell two thick, short muscles (Fig. 82, 2, 3; Fig. 83, 2 *a*) extend across from valve to valve, and resist the spreading action of the hinge-ligament.

The Mantle and the Mantle-Cavity. When the valves are shut they inclose a considerable space besides the body proper. Fig. 82 represents the most important organs as they might lie in the hollow of the right valve. Fitting close to the inner surface of the valves is the *mantle* (Fig. 82, 4). Except at the edge, where the *mantle-folds* (halves) unite, the mantle is quite thin; its chief use is to secrete the calcareous substance of which the shell is composed. The shell is deposited in three layers (Fig. 83, 3, 4, 5), — the outer layer called the *periostracum*, the middle layer called the *prismatic* layer, and the inner layer called the *nacreous* or pearly layer. After the shell is formed at the edge the thin part of the mantle-folds continues to deposit the nacreous layer, which is sometimes called mother-of-pearl.

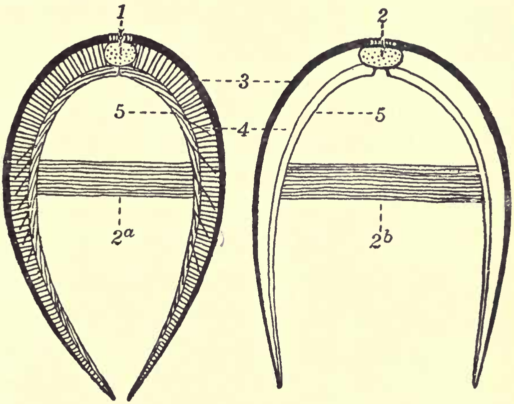


Fig. 83. Mechanism for opening and closing Mussel-Shell

A, valves of mussel closed; *B*, valves of mussel open: 1, 2, hinge-ligament; 2^a, adductor muscle contracted; 2^b, adductor muscle relaxed; 3, outer layer of shell; 4, middle layer of shell; 5, inner (mother-of-pearl) layer

(From Lang's *Lehrbuch*)

The mantle-folds inclose a *mantle-cavity*. An opening at the anterior end of the mantle-cavity allows the *foot* (Fig. 82, 5), the single locomotor organ, to be extended to the outside. At the posterior end of the mantle-cavity is situated the double-tubed *siphon* (Fig. 82, 6). Only the lower tube of the siphon is connected directly with the mantle-cavity. This siphon enables Mya to lie buried, anterior end down, in the mud and sand, still maintaining communication with the food-laden and air-laden water above. In large specimens of this clam the siphon is over 25 cm. (10 in.) long.

The Digestive System. The ventral opening of the siphon (Fig. 82, 7) is surrounded by many short tentacles which guard the passage. An ingoing current is created in the water by cilia on the gills. Ordinarily only microscopic food passes through this incurrent opening of the siphon. In the mantle-cavity the particles of food are carried forward over the gills and along the mantle till they come within range of the waving *palps*, or mouth-appendages (Fig. 82, 9).

The *mouth-opening* (Fig. 82, 10) is situated between the four palps, and is very small. It has no organs of any kind for seizing or chewing food; none are needed. The food once swallowed passes through the short *œsophagus* to the *stomach* (Fig. 82, 11). Surrounding the stomach is the large, paired *digestive gland* (Fig. 82, 12). which secretes the digestive fluid. Situated in the end of the stomach, and in the anterior end of the intestine, we find, in Mya arenaria, and in many species related to it, an organ called the *crystalline style* (Fig. 82, 14). In Mya this structure is three or four inches long. It is soft and clear like thick, colorless jelly, and lies in a long, thin-walled sac opening into the stomach.

Many theories have been advanced to account for the existence of the crystalline style. Recently (1901) the nature of the structure was investigated by Professor Mitra, a physiological chemist living in Calcutta, India. He has published an account based on experimental evidence, which appears to be satisfactory. His conclusion is that the crystalline style of a certain fresh-water mussel (*An'odon*) is the condensed secretion of the digestive gland; its function is to convert starch into sugar. After a period of feeding and subsequent digestion the style disappears and is later formed anew.

The *intestine* (Fig. 82, 13) coils and twists in many planes from the posterior end of the stomach to the point where it penetrates the heart. The penetration of the heart by the intestine is of common occurrence in the class to which Mya belongs, but it occurs in no other class of animals. The part of the alimentary canal from the heart to the *anus* (Fig. 82, 16) is called the *rectum* (Fig. 82, 15). The rectum is inclosed in a large, spindle-shaped organ (Fig. 82, 17) of unassigned name and unknown function.

The Circulatory, Respiratory, and Excretory Systems. When the food is absorbed by the wall of the intestine it passes into small blood-spaces filled with colorless blood. The blood with the contained food then passes into the open ends of small blood-vessels. These blood-vessels lead (in certain near relatives of Mya which have been studied more fully) to a large blood-space below the *pericardium* (Fig. 82, 18), the sac which incloses the heart. From the blood-space (not shown in the figure) blood passes by vessels to the *nephridia* (kidneys). The nephridia in Mya arenaria lie one on either side near the heart. The anterior end of the left nephridium is indicated at Fig. 82, 19. The rest of the organ could not be shown in the drawing.

The nephridia are spongy, brownish organs of great complexity. They are sometimes referred to under the name "organs of Bojanus." The old-time anatomist, Bojanus, discovered the structures, but he made a most natural mistake in thinking that they were the lungs of the animal, since they look like lungs and lie very near the heart. Other anatomists gave the name "organs of Bojanus," and later investigators found that the organs were alike in structure and in function to the nephridia of simpler animals. Each nephridium of the clam opens by one end into the pericardium. The other end of each nephridium opens into the mantle-cavity just posterior to the digestive gland.

As the blood-vessels in the nephridia divide into capillaries, the nitrogenous waste of the body (uric acid) passes into the nephridial tube and is carried out into the mantle-cavity. The small blood-vessels, reuniting into large vessels, convey the partially purified blood into a vessel that runs along the line of attachment of the gills.

There are four of these *gills* and they hang like double curtains along the right and left sides of the body (Fig. 82, 20). The oxygen coming into the mantle-cavity with the water, through the incurrent tube of the siphon, passes over the floating gills. They are thin and soft, and are thus adapted for the ready passage of oxygen to the blood-vessels inside.

In the blood the oxygen combines with *hæmocyanin*, a substance analogous to *hæmoglobin* (see p. 203). At the same time the waste carbon dioxide in the blood is given off to the water in the mantle-cavity. The mantle-folds, as well as the gills, take part in respiration. It is possible for them to do so because of their rich supply of superficial blood-vessels.

Returning from the gills and the mantle, the blood freed of carbon dioxide is carried to the *right* (Fig. 82, 21) and *left auricles* of the heart. These thin-walled, sac-like reservoirs force the blood into the *ventricle* (Fig. 82, 22) of the heart through valve-guarded openings on either side (Fig. 82, 23). The heart contracts and forces the blood both forward and backward through *arteries*. The anterior artery lies above the intestine (Fig. 82, 24), and the posterior artery lies below the rectum (Fig. 82, 25). Both arteries branch into smaller arteries in all parts of the body. The blood flows from the open ends of the smallest arteries into blood-spaces, from which it is once more collected and carried to the purifying organs in the manner already described.

The Excurrent Tube. Besides the rows of cilia which carry food from the region of the incurrent tube to the mouth, there are rows of cilia on the body and along the mid-ventral line of the mantle, and it is known that these cilia wave toward the incurrent tube. Food that has been rejected, or waste that has accumulated, may be carried by the out-waving cilia to the base of the incurrent tube. By muscular contraction of the siphon at its base these substances may be expelled through the tube. The dorsal tube of the siphon, however, is the customary path of exit for substances that are not used by the organism. All the undigested substances that pass through the intestine must leave the animal by the dorsal tube. In addition, it is likely that wastes from the nephridia, and from the gills and mantle, may pass from the mantle-cavity through a slit-like opening (Fig. 82, 26) at the base of the gills, and be carried out with the unused materials.

The Nervous System. Lying on the right and left sides of the œsophagus, just posterior to the mouth, is a pair of *cerebro-pleural ganglia* (Fig. 82, 27). They are joined by a *cerebral commissure* running over the œsophagus. As the name of the ganglia implies, there are two ganglia joined in each nerve-mass. One pair controls the "head" region; the other pair controls the sides of the body near by. The cerebro-pleural ganglia are joined to the *pedal* (foot) *ganglion* (Fig. 82, 28) by two *connectives*, one on either side (Fig. 82, 29). The pedal ganglion controls the movements of the foot. The *visceral ganglion* (Fig. 82, 30) is joined to the cerebro-pleural ganglia by a pair of *cerebro-visceral connectives* (Fig. 82, 31). The visceral ganglion controls the organs in the posterior region of the body.

The Reproductive System. The pair of large glands (Fig. 82, 32), which in male and female clams contains spermatozoa or the eggs, lies in the midst of the coils of the intestine. Each gland has a short, slender tube, with an external opening (not shown) near the opening of the nephridium, just below the attachment of the gills.

Development. The very early history of the young Mya arenaria has not been studied. We know, however, that after a short period of development and growth young long-neck clams swim about on the surface of the water. Soon after the appearance of their shell they sink to the bottom. If they are fortunate enough to fall near the shore-line, they anchor themselves to a seaweed, or to a pebble, by a tough, gelatinous thread (Fig. 84, 3) which is secreted by a gland at the base of the foot (Fig. 84, 1). This thread is called the *byssus*. In certain mussels found in the sea the byssus is a permanent and very complicated organ of the adult, but in Mya arenaria it disappears when the clam is about 5 millimeters ($\frac{1}{5}$ inch) long. At that time the animal burrows into the mud and sand, where it usually remains permanently.

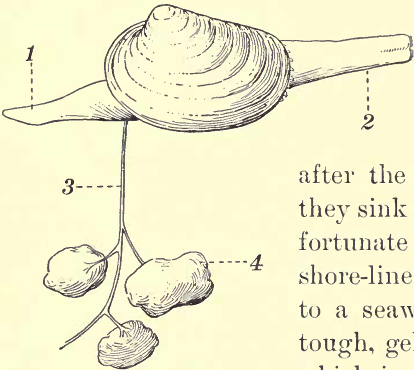


Fig. 84. Young Long-Neck Clam. (After J. L. Kellogg)

1, foot; 2, siphon; 3, byssus-thread; 4, pebbles

Relation to Environment. The adult Mya arenaria lives in soft mud and sand between high-tide line and a few feet beyond low-tide line. The reason the clam lives in that situation is because food is most abundant there. Lying almost helpless in its mold of mud, the long-neck clam is rendered in a measure independent of conditions outside, as long as the currents of water carry the bountiful supplies of food over its burrow.

If a young clam escapes the danger of being carried out to sea during its pelagic life, it is safe for a while when, on sinking to the bottom, it anchors to some fixed or heavy object with its byssus-thread. There it encounters dangers from food-hunting fish. Still more dangerous are the storms that carry waves of water far up the beach and leave to destruction many kinds of animals that happen to be borne along. At the same time countless young of the clams that escape being carried out must be smothered by the shifting sand and mud.

As the adult stage approaches the dangers of existence become less and less, until man himself interferes with the natural balance of chances in the clam's life. In certain parts of the Atlantic coast, especially in the vicinity of large cities, the species is fast being exterminated. Although the clam is not as highly esteemed as an article of human food as its relative the oyster, it is nevertheless of great value. Officers of the Bureau of Fisheries have considered the matter of restricting the digging of clams, and also various means of tiding the young over the danger-points in their lives.

The American Oyster

Habitat and Distribution. The American oyster (*Os'trea virginia'na*, Fig. 85) is found in shallow to deep water along the Atlantic coast from the Gulf of Mexico to Massachusetts Bay. As the artist has shown in the picture, the animal lies attached to the bottom, frequently to another oyster-shell. Although many oysters may live thus fastened to each other, there is no organic connection between them. They sometimes form clumps so large and heavy that the basal ones sink into the mud and die. The valves of the living ones extend outward at any angle. When oysters are not crowded in the "bed," the usual method of living is the one shown in the illustration. There the valves extend horizontally, and we can distinguish an upper and a lower valve. The lower valve is always much larger and deeper than the upper one. The lower one is the left valve.

Comparison with the Clam. The internal organs of Ostrea virginiana and Mya arenaria are very much alike. The large, dark-brown digestive gland, the coiled intestine, the three-chambered heart, and the reproductive glands have a common plan in the two species. A noticeable difference is the entire absence of a foot in the oyster. Applying the principle of adaptation, we can readily explain the absence of that organ. The two animals are different also in the number of adductor muscles. In the clam there are two; in the oyster only one. The muscle-scar on the inner surface of the valves of an oyster is a dark blotch. As the oyster grows from season to season the location of the shell-closing muscle changes

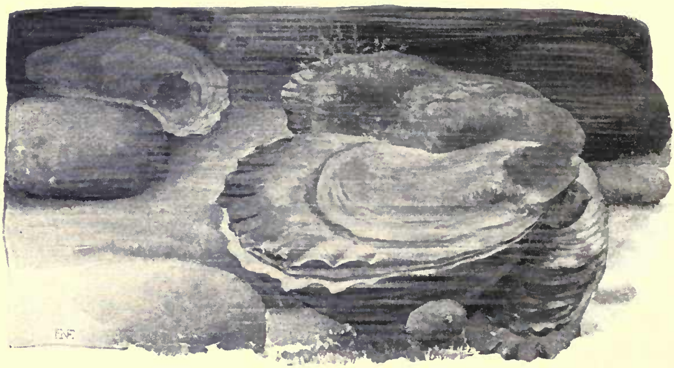


FIG. 85. Group of Living Oysters. Reduced

to meet the necessity of performing its function most advantageously. In a lot of a dozen oyster-valves the observer may find several which indicate this change. In some valves all trace of the change is concealed by the thick layer of mother-of-pearl laid down by the mantle after the muscle altered its position.

Development. In the months of May, June, and July, in the latitude of Baltimore, the male and female oysters send out into the water their spermatozoa and their eggs. Professor Brooks, of Johns Hopkins University, estimates the number of eggs which a female oyster may yield in one season to be at least nine million. "The number of male cells," he says, "is great beyond all powers of expression." Of course we should expect that in spite of the countless spermatozoa, many eggs would never be fertilized at all, on account of their being carried away by unfavorable currents. Eggs that are not carried away fall to the bottom naturally. Those eggs which are fertilized swim to the surface as larvæ after a few hours' development. There surface-fish may, as Professor Brooks suggests, "gulp down in a few seconds oysters equal in number to the population of Baltimore."

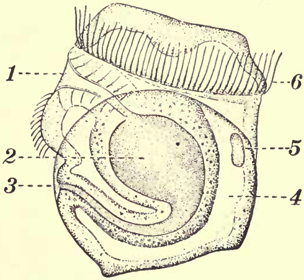


Fig. 86. Oyster Larva. Much enlarged. (After Mœbius)

1, mouth; 2, stomach; 3, anus; 4, shell; 5, adductor muscle; 6, circle of cilia

Within one to six days after fertilization the oyster "fry" (swimming larvæ, Fig. 86) sink to the bottom again and affix themselves by the margin of the left mantle-fold to whatever solid object they happen to touch. At this time they are about .3 mm. ($\frac{1}{80}$ in.) long. For a few weeks after beginning their stationary life they are liable to be crunched to death by voracious crabs, — among others, the blue crab (Fig. 71).

Economic Importance. The largest and most important "oyster-farms" along our coast are in Chesapeake Bay. There and elsewhere the beds have been surveyed and leased under laws of the states. So vast is the oyster-fishing industry in this country that millions of dollars are paid annually by the markets of the large cities for these "esculent bivalves." On the coasts of Holland, Belgium, and France far greater care is taken of their species (*Ostrea ed'ulis*) than we take of ours; but the natural conditions here are superior to the natural conditions there.

Relation to Environment. According to the investigations of Professor Brooks, Professor Ryder, and others, oysters are to be found most abundantly in the quiet, semistagnant water of shallow inlets. Into such inlets slowly flowing creeks enter, giving to the water of the inlet a brackish quality. When food consisting of microscopic plants and animals is carried to the oyster by the natural currents in the water, it may enter at any point between the separate folds of the mantle. Cilia on the inner surface of the mantle-folds, and on the four gills, sweep the minute organisms forward to the mouth, which lies near the hinge. The four palps aid in the process. In brackish water the most important food-organism of the oyster multiplies in vast invisible hordes. These organisms are plants called diatoms. Diatoms live in the soft mud at the bottom, and are carried by the water-currents within range of the cilia in the oyster's mantle-folds.

In times of storm the home of the oysters' food may become a source of great danger to them. Once covered with mud or with shifting sand, the life of a bed of oysters is at an end. At the mouths of rapidly flowing rivers no oysters are to be found, chiefly because the silt (fine sediment) and the débris of decaying plants are unfavorable to the growth of the animal.

Aside from the physical agencies which are favorable or unfavorable to oysters, there are many animals which come into definite and usually unfavorable relations to them. Only one of these animals, so far as known, is anything but harmful to the oyster. That one is a little crab, about 13 millimeters ($\frac{1}{2}$ inch) wide, which spends its life in the mantle-cavity of its messmate. The greatest enemy of the adult oyster is the starfish (Fig. 118). There are various boring-snails, which make round holes through one of the valves with their rasping-tongues and draw out what they need of the soft parts (compare Fig. 99). Another enemy is the boring-sponge, which, as it grows, makes holes in the valves by a secretion which it produces. Like most other animals, the oyster has its parasites. With all these facts before us, the statement of Professor Möbius regarding the European oyster, that each oyster when born has $\frac{1}{1145000}$ of a chance to survive and reach adult age, seems well within reason.

The Scallop

Habitat and Distribution. Of all the "shell-fish" that inhabit the shallow waters of the Atlantic coast of our country, none is more beautiful in color or in line than the common scallop, *Pec'ten irra'dians* (Fig. 87). Scallops are abundant among the eel-grass of shallow bays and inlets from the Gulf of Mexico to Massachusetts Bay. Above the latter region the waters are made colder by the Arctic currents. Pecten irradians and many other species of sea-animals do not live north of Cape Cod. There are, however, many species of animals that flourish best in the cold waters of Maine and the maritime provinces of Canada.

Relation to Environment. The very young scallop holds to some fixed object after the manner of a young soft-shell clam (Fig. 84). The adult scallop has no byssus, and only the rudiment of a foot. The scallop in the foreground of the picture is in what we might call the attitude of rest. It has released its single adductor muscle, which, we may say in passing, is the only part of the animal sold for food. The mantle-folds of the resting scallop expand, showing at the margin slender tentacles and a variable number of delicate cobalt-blue eyes. If a person causes a shadow to pass over the margin of the mantle, the mantle is withdrawn and sometimes the valves are closed. The same experiment may be tried on the oyster with similar results, although the oyster has no eyes at all. Invisible sense-organs in that animal respond to the stimulus of light.

While feeding and breathing, the tentacles of the scallop aid the cilia of the mantle, gills, and palps in conveying food to the mouth. At such times the spores of various seaweeds and the young of certain snails (*Crepid'ula*, on scallop in foreground, Fig. 87) may find a surface of attachment on one of the valves. These organisms have an advantage over stationary individuals of the same species, in being attached to a movable support, for, when the scallop swims about, the messmates are carried to new and possibly better stores of food.

If one were to reason from the general appearance of the scallop which part should go forward when the animal swims, it is very likely that the conclusion

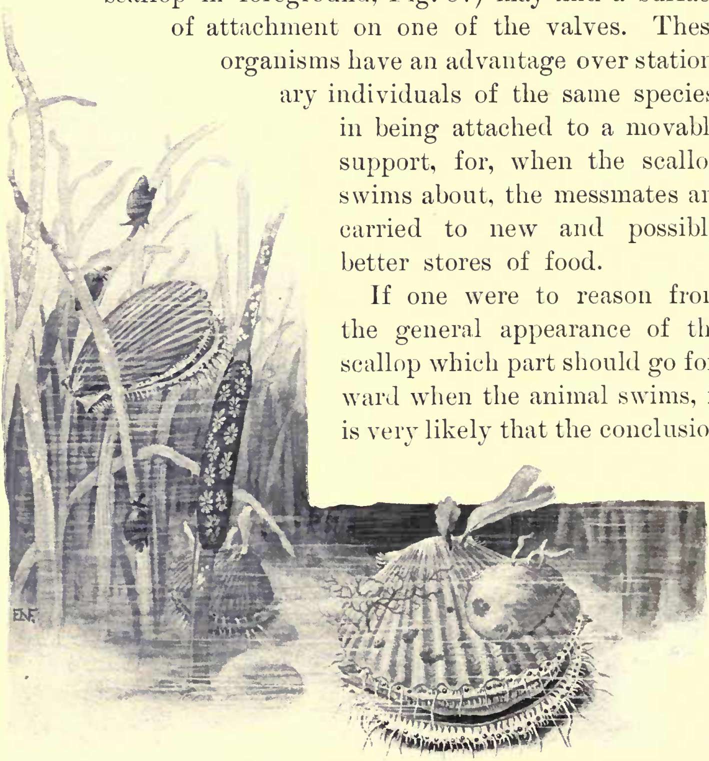


Fig. 87. Group of Living Scallops. × ½

would be different from the actual performance. The attitude of a swimming scallop is portrayed in the upper left-hand part of the illustration. In the act of swimming the valves open and close quickly, by the alternate action of the hinge-ligament and the large adductor muscle. On closing, the valves catch a quantity of water between the mantle-folds. The water escapes under pressure from within, through a round opening at either end of the straight flange of the hinge. The resulting action of these jets of water backward, against the body of water outside, is to force the larger and broader end of the animal forward. Locomotion is not in a direct line, but over a zigzag course. When the scallop ceases swimming it immediately falls to the bottom. The animal is not what one would call a skillful swimmer, although its movements are very interesting to observe.

The Fresh-Water Mussel

Habitat and Distribution. In fresh waters generally, wherever sufficient carbonate of lime is carried in solution, one may find mussels living nearly covered in sand and mud. The species represented in Fig. 88, *U'nio complana'ta*, is distributed in the rivers and brooks of the entire country.

Comparison with Other Forms. The valves of the mussel are equal, like those of the clam and the scallop. The valves of the fresh-water species are held together by a hinge-ligament, aided by two pearl-covered ridges running parallel and fitting into grooves. The mantle-folds are not united, as they are in the clam. At two adjoining places in the posterior region the rim of the mantle-folds is fringed with short tentacles. Dorsal and ventral tubes are formed by the meeting of opposite edges at the places where the tentacles occur. Food and oxygen are carried in by the ventral tube, and undigested substances are carried out by the dorsal tube. We may speak of the siphon of the mussel, but as a matter of strict accuracy the mussel does not have a siphon, in the sense that the clam possesses one. The foot of the mussel is large and muscular. It enables the animal to plow its way through mud or even through heavy gravel. The gills and the palps are practically identical in structure in the mussel, the clam, the oyster, and the scallop. The internal organs also have the same general plan of structure in the four animals named. There are two adductor muscles in the mussel. The sexes are separate.

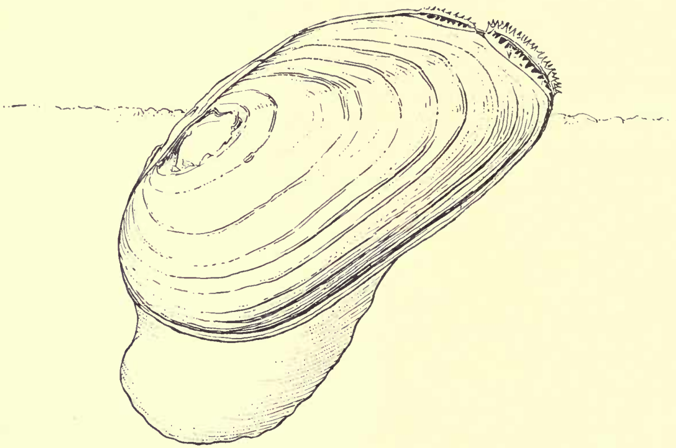


FIG. 88. Living Fresh-Water Mussel. × ½

Development. At least two genera of fresh-water mussels carry their young in their gills, which are open dorsally on the inside. Such an arrangement is necessary because the currents in rivers all go one way, and would carry the helpless young out to sea. At a certain stage the well-developed larvæ escape from the brood-pouch of the female mussel and fall to the bottom. Fish "nosing" along the river-bed touch the floating byssus-thread of the young mussel, which at that stage is called the *glochidium* (Fig. 89). The thread

(Fig. 89, 4) clings to the surface of the fish's gill or skin, and the little hook (Fig. 89, 3) on the edge of either valve sinks into the flesh. For several weeks the glochidium is transported on the fish, during which time it may be carried into another river, even by way of the sea. When the end of fixed development comes, the protecting coat is dissolved and the little mussel falls to the bottom again. If this happens in a favorable place, it burrows into the mud and begins the life of its adult kin.

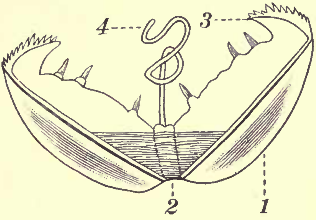


FIG. 89. Larva of Mussel. Much enlarged. (After Balfour)

1, shell; 2, adductor muscle; 3, larval hook; 4, byssus-thread

Economic Importance. The distribution of fresh-water mussels has become a matter of considerable economic importance, especially in the states of Iowa and Illinois. Factories have been established there for the purpose of making pearl buttons from the valves. True pearls of fine quality have been found in many species of mussels in all parts of the Mississippi valley.

The opinion has been held by many that if grains of sand find lodgment between the mantle and the valve of a mussel or an oyster, the mantle will surround the particle with layers of pearl, like the substance normally secreted by the species to line its valves, and thus form pearls. We have heard stories of these valuable products being formed by pearl-oyster fishermen, who inserted grains of sand between the valve and the mantle of the famous pearl-oyster of the Arabian Gulf, but we have no evidence that a grain of sand has ever been found in a *true* pearl. Grains of sand only cause rough spots in the layer of mother-of-pearl.

The investigations of Professor Jameson, of South Africa, in 1902, afford the first conclusive evidence regarding the origin of pearls in the common edible sea-water mussel, *My'tilus ed'ulis* (in Fig. 126). A trematode parasitic worm (Fig. 111) in the larval stage creeps between the valve and the mantle-fold. In its wanderings it starts to bore through the mantle-fold. The tissue is soft, but the parasite may rest for a while among the loosely connected cells. In that case it is immediately surrounded by a minute fold of the outer *epithelium* (surface-cells) of the mantle. About the trematode larva as a center the epithelium (Fig. 90, 2) begins to secrete a substance which, on hardening, becomes a pearl (Fig. 90, 5). Before the hardening takes place the larva may move to some other part of the mantle-fold. Again it may be the stimulus for producing a pearl.

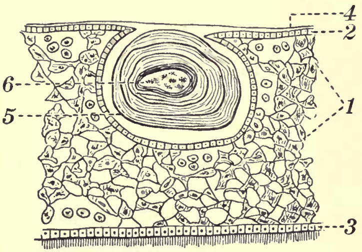


Fig. 90. Section of Mantle-Fold of Mussel showing how a Pearl is formed. (After Jameson)

1, cells of mantle; 2, external epithelium of mantle; 3, internal (ciliated) epithelium; 4, position of shell; 5, pearl; 6, remains of parasite

Examination of pearls often reveals a small particle of matter about which the pearl was formed in layers. Professor Jameson thinks the substance at the center of the pearls he has examined is the body-waste, or excrement, of the parasite (Fig. 90, 6), except in those pearls in which he has found the dead body of the parasite itself. Even the temporary presence of the parasite is a sufficient stimulus for the production of a pearl. The pearl may get so large that it breaks through the outer epithelium of the mantle-fold and becomes attached to the valve itself. If the pearl breaks through the inner (ciliated) epithelium (Fig. 90, 3) of the mantle-fold, it falls into the mantle-cavity, and finally to the outside, which accounts for the fact that pearls are often found in the sand.

Relation to Environment. The distribution of Unio complanata in the bed of a river is determined somewhat definitely by the position of the strongest current. It is well known that in a crooked river the main current does not follow the middle line of the stream, but sweeps from bank to bank diagonally across the middle. The greater amount of food is carried along by the swifter water, and hence, unless the stream is too swift, the mussels find it advantageous to range themselves along the line of the most abundant food-supply.

Mussels are considered by some to be of great service to man and other animals because of their habit of devouring the decaying organic substances so abundant in rivers which flow past large cities. There is good reason for believing, however, that sewage is not the natural food of mussels, and that they will flourish better in water of natural purity. In fact, it has been positively determined that mussels do not live near the mouth of a large sewer.

Definition of Pelecypoda

The four animals described in this chapter are representatives of a class called by various authors *Lamellibranch'ia*, *Aceph'ala*, or *Pelecyp'oda* (Gr. *pelekys*, hatchet; *pous* (*pod*), foot). They are also called bivalves because the shell is in two pieces. Lamellibranchia signifies that the animals have gills (branchiæ) which are thin, like plates (lamellæ). Acephala means "without a head."

Pelecypoda are usually bilaterally symmetrical animals with an external skeleton composed of two more or less nearly equal valves. They have no internal skeleton. The body is without a head and is not divided into somites. There are no segmented appendages. The mantle-folds surround the body proper and secrete the shell substance. Locomotion is most frequently accomplished by a single muscular organ, the hatchet-shaped foot. The valves are held together by a hinge-ligament, aided sometimes by ridge-like processes fitting into grooves. The valves are closed by one, or two, adductor muscles.

Four palps surround the mouth and carry the food inward. The œsophagus is short. The stomach receives the secretion from a pair of digestive glands. The intestine coils several times and ends posteriorly. The circulatory system is nearly complete. There are two auricles and one ventricle in the heart. The pair of glands of the reproductive system in male and female individuals seems to differ only in microscopic structure. In some species the sexes are separate. In others the individuals are hermaphroditic; that is, the male and female sexual glands are present in the same animal.

CHAPTER XV

ALLIES OF THE PELECYPODA: MOLLUSCA

> The frugal snail, with forecast of repose,
> Carries his house with him where'er he goes.
>
> CHARLES LAMB.

The Pond-Snail. Any one of several genera and species of snails that live in fresh water might be given the name "pond-snail" with equal accuracy. The one represented in Fig. 91 (*Phy'sa heterostro'pha*) is quite common not only in ponds but in rivers as well.

Externally the most noticeable feature of the pond-snail is its thin, spiral shell. This structure is made of the same material as the shell of bivalves. A large portion of the animal's body fills the "mouth" of the shell and extends spirally toward the top. The direction of the spiral (or spire) in Physa is left-handed, — an unusual condition. The spire of a left-handed shell, starting with the top toward the observer, turns contrary to the movement of the hands of a clock; the spire of a right-handed shell turns with the hands of a clock. Between the shell and the body-wall lies the mantle, which throughout life continues the growth of the shell in the characteristic spiral direction.

When the snail is disturbed it draws its shell down over the entire body; but while feeding, as shown in the picture, one can see the long, muscular foot, broad in front and pointed behind. The anterior region of the body is the head, more or less sharply marked off from what lies behind. The mouth opens beneath an extensile upper lip. In the mouth is a short, muscular tongue, on which grows a long but minute ribbon of rasp-like teeth. The pond-snail uses this rasping-tongue, running it in and out, to tear into bits the soft plant tissues on which it feeds. A most interesting experience is to watch a pond-snail as it crawls slowly up

FIG. 91. Group of Living Pond-Snails. Natural size

the side of an aquarium, feeding on the microscopic plants as it goes. At such times one can see the mouth open and the tongue sweep gracefully out and in, with tiny, rhythmic movements.

The two tentacles are organs of touch. The eyes lie one in front of either tentacle at its base. On the right side, near the head, are the single openings of the intestine, the nephridium, and the sexual glands. Also on the right side, and partly beneath the edge of the shell, is an aperture which opens and closes over a small hollow space in the body. This space is the so-called "lung" of the pond-snail. The lung is adapted to using the oxygen of the atmosphere. Any one who owns an aquarium containing snails may observe them crawling up the side of the vessel on their way to the surface. When they arrive there they remain for some time, opening and closing the lung to the air. In aquaria which have a supply of water-plants growing in them, the pond-snail does not appear to go to the surface so often. It is well known that plants give off oxygen. Some of this oxygen held in the water may pass through the snail's skin, which is thin and soft. The waste carbon dioxide of the snail is discharged into the water, and may be used by water-plants as raw food-material.

It is not uncommon to see a pond-snail crawling upside down at the surface of the water. The explanation of this curious phenomenon is the same as the explanation of how they can get along on any kind of a surface. Just below the mouth is the opening of a gland, which extends through the middle of the foot near the lower surface. If we look closely at the inverted snail, we can see the wall of this foot-gland contracting with a wave-like movement in the act of sending the secreted mucus (slime) forward to be poured out at the opening. The mucus spreads out a short distance on the water, or blade of water-plant, or submerged pebble, and forms a bed over which the animal moves.

When the foot is extended in locomotion the pond-snail weighs less than an equal volume of water. If the animal releases its hold on an object at the bottom, it floats to the surface quickly. Conversely, if the animal voluntarily (or under visible stimulus) releases its hold on the surface of the water, it draws the entire body into the shell and quickly falls to the bottom. In the second instance the weight of the snail's body is greater than the weight of an equal volume of water. One might well ask why the pond-snail does n't migrate up and down in this way habitually. We can only say that perhaps the sudden change of pressure from a great to a less amount in going up, and from a small to a greater amount in going down, is not so favorable as a slower rate of change would be.

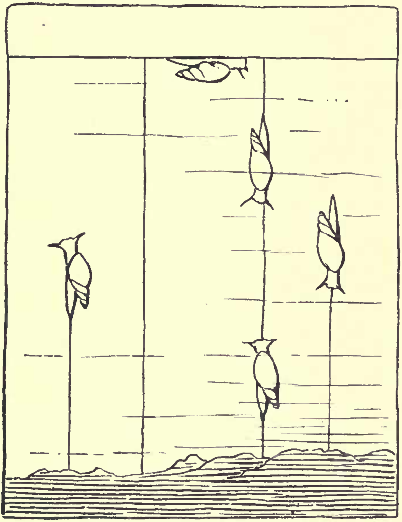


Fig. 92. Mucus-Threads of Pond-Snail (*Limnæ'a*) in Water. Reduced. (After Kew)

We find some confirmation of this theory in the existence of vertical threads of mucus in snail aquaria and in ponds (Fig. 92). A snail on leaving the bottom may pour out mucus from its foot-gland in the usual way. The mucus fastened at the bottom will be paid out in the form of a thread, as the animal floats upward, slowly held back by this thread. When the snail gets to the surface the thread is moored there in a patch of mucus. Each thread thus formed becomes a permanent pathway, tending to increase in thickness and in strength as the snail makes use of it.

In the spring and summer months the pond-snail lays eggs even in captivity. The sexual gland is hermaphroditic, hence every individual is likely to deposit eggs. The eggs may be found on the branches of water-plants, or even on the perpendicular sides of a glass aquarium, imbedded in an elliptical, clear, gelatinous mass from two millimeters to six millimeters long. In each mass from five or six to twenty-five eggs may be distinguished.

The Land-Snail. One of the commonest of the land-snails in America is the one shown in Fig. 93 (*He'lix nebulo'sa*). Like its many kindred species of the genus Helix, it lives in moist, protected places during the day, and comes out to feed at night. Frequently it leaves its hiding-place in cloudy, damp, but not in rainy, weather.

In general features, the organs to be noted on the exterior of this animal are the same as in the pond-snail. The openings of all the internal organs occur in the same position in both animals. There are four tentacles in Helix, — an upper, long pair bearing the eyes, and a lower, short pair, which are the organs of touch. The edge of the mantle is thickened to form a collar.

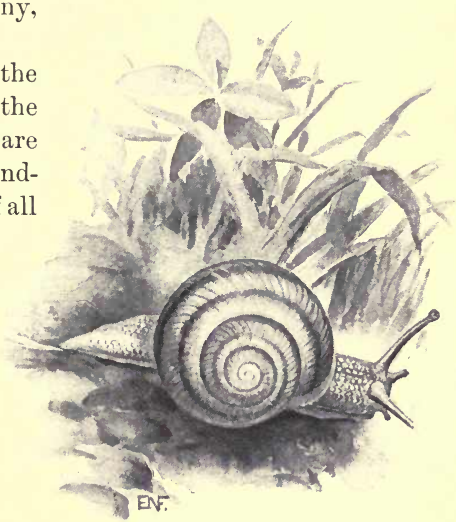


FIG. 93. Living Land-Snail. Natural size

In the fall of the year, about the time of frost, the land-snail ceases to eat, becomes inactive, and makes preparation for the winter's sleep, or hibernation. Crawling to the protected side of an object which has a smooth surface, the animal withdraws into its shell, allowing the edge to fit closely to the object. Then certain glands in the collar secrete mucus, which flows from all sides over the under surface of the foot, between it and the supporting surface.

When the membrane dries it has the appearance of stiff, oiled paper of considerable toughness. It is called the *epiphragm.* It is supposed that the epiphragm aids in retaining the body-heat during the four to six months of sleep. Metabolism (see p. 206) continues through all that time, but at a much reduced rate. A very small hole is to be found in the epiphragm, in one species of Helix at least, just below the lung-aperture. Through this oxygen and carbon dioxide may continue to pass. With the returning warmth of spring the snail bursts the epiphragm and recommences active life.

The Garden-Slug. The particular species of garden-slug, the habits of which are suggested in Fig. 94, is *Li'max max'imus.* It is a native of Europe, not of America, and since its introduction here has become a more unwelcome guest in greenhouses than any other species of slug or snail. As yet it is not widely distributed from the vicinity of New York and Boston.

In brief terms we may describe a slug as a snail with a rudimentary shell. The elliptical plate of muscle on the dorsal surface of Limax is all that is left of the mantle. In the process of degeneration, which we may well suppose has occupied thousands of years, the mantle folded back over the shell as the latter decreased in size. If we examine the interior of the mantle, we find a thin, calcareous plate, which is undoubtedly the rudimentary shell.

Aside from the difference in the size and form of the shell, Limax maximus and Helix nebulosa are very much alike. The body of Limax is straightened out, but the organs which in Helix have openings on the right side of the body also have openings on the right side in Limax. These are the generative opening just back of the right eye-stalk, the anus, and the nephridial opening near the lung-aperture. The garden-slug, like the snails, has a rasping-tongue.

If a person examines in daylight the under side of boxes or bunches of straw that usually collect about a greenhouse, he will find within the range of the animal's distribution many specimens with their heads contracted to the body, holding to the surface of the thing which conceals them. Frequently after a night's forage on the tender parts of greenhouse plants, they go no farther away than the bottom of the flower-pot. Reliable observers have marked specimens and have found that these creatures return night after night to a particularly succulent plant, such as the Amaryllis in the picture. It is thought by some that their "sense of direction" lies in the ability to smell their food-plant. Some authors believe that the organ of smell lies at or near the end of

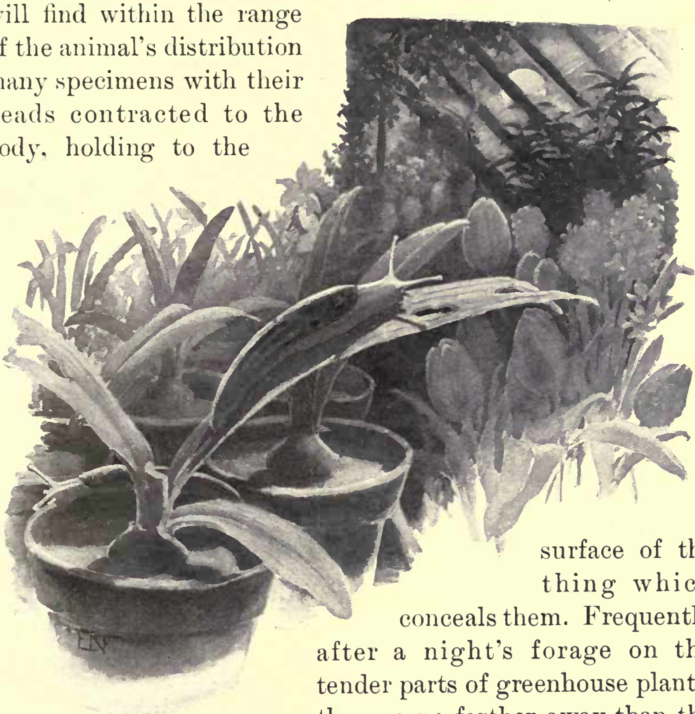


FIG. 94. Garden-Slug feeding at Night. × ½

the eye-stalk; others are inclined to think that the animal has a more definite organ of smell in the *osphradium*. This organ occurs on the mantle-edge near the lung-aperture.

The ravages of Limax maximus are not serious, if the florist does not allow refuse to collect about his buildings. Many adopt the method of scattering ashes or cinders about the plants to be especially protected. A slug crawling into such an obstruction is stimulated by the dryness of the ashes, or the roughness of the cinders, to secrete mucus from the glands that occur in the skin. This mucus is like that which is secreted from its foot-gland while crawling. Owing to the unusual amount of mucus given off at such times, the animal dies from exhaustion, and from suffocation by the drying of its skin.

From the beginning of September to the end of November Limax maximus lays its eggs in its place of hiding. The eggs have about one half the diameter of dried peas. They are quite spherical. The shell is translucent and is tough and membranous. Twenty-five or thirty eggs are deposited at one time, and left on the ground in a loose, agglutinated mass. The embryos of the early eggs hatch within two or three weeks, while eggs deposited late probably do not hatch until the following spring. The garden-slug is hermaphroditic. The eggs and spermatozoa in each individual mature at different times, and consequently the union of two individuals is necessary for the fertilization of the eggs.

Garden-slugs that live out-of-doors burrow into the ground and curl up when the coldest weather comes. Those in greenhouses remain active throughout the year.

The Oyster-Drill. A few minutes' walk along almost any pebbly beach between Florida and the Gulf of St. Lawrence would afford a collector the opportunity of observing the subject of this description, the oyster-drill (*Urosal'pinx cine'rea*, Fig. 99). In such a walk the artist discovered the unfortunate periwinkle at the left of the picture, with the oyster-drill of the foreground engaged in devouring the soft parts of its victim through the hole made in the thick shell. For the purposes of illustration the oyster-drill was placed on another periwinkle in the same position it occupied on the first when discovered. In deep water the oyster-drill devotes itself to the business which gave it the name it bears. There are several other species of snails, however, which have the same habit of boring through the oyster's valves and feeding on the soft parts.

The oyster-drill has organs not found in the snails already described in this chapter. In a little groove in the "mouth" of the shell lies a small tube called the *siphon*, which carries water to a gill-chamber, where the blood is supplied with oxygen. Another organ is a horny plate growing on top of the posterior end of the foot. When the foot is withdrawn into the shell, the horny plate, which is called the *operculum* (a lid, or cover), is drawn into the mouth of the shell. The operculum is of great service to the animal in keeping out unwelcome visitors.

The oyster-drill, in common with all other species of snails that have their habitat on the seashore, possesses a very thick shell, adapted to the severe conditions of life there. The sand and pebbles are constantly shifting under the pressure of the waves, and only those snails that have thick shells can endure the conditions.

The Periwinkle. The periwinkle, a littoral (shore) species (*Littori'na litto'rea*, Fig. 99), is a native of Europe. Its presence here is accounted for by the supposition that specimens were accidentally thrown in with the gravel used for ballast on ocean-going vessels, and thrown out again when the vessel reached its port in America. The first specimens noticed in America by conchologists (students of shells) were reported at Halifax, Nova Scotia, in 1857. Since that time the periwinkle has been making its way down the coast. It may now be found in southern waters. The new home in America seems to be especially favorable for the periwinkle, for on the rocky coast of New England there are so many of them that on first impression there appears to be no other species.

The periwinkle depends on plant-food altogether. It is reported that the oystermen of Whitstable, England, at the mouth of the Thames River, collect these snails in large quantities and throw them over the oyster-beds in order to be rid of the excess growth of seaweeds.

On account of its great abundance the periwinkle is much used as an article of human food in England and on the Continent. It is one of the many species of snails and slugs used as food, especially by the French people.

The Nudibranch. The strange-looking creature shown in Fig. 95, *Dendrono'tus arbores'cens*, is to be found on seaweeds and under submerged rocks along the North Atlantic coast.

FIG. 95. Photograph of Living Nudibranch. Natural size

The general form of a slug is, in this animal, modified by the occurrence of tree-like processes growing on the upper part of the body, whence the generic and specific names. These processes are called *cerata*, and to some extent are used in respiration. Being thin, oxygen can pass into the animal through them, and the waste carbon dioxide can pass out. The group of animals to which they belong is called *Nudibran'chia*, in reference to the fact that their gills are naked. There is no indication of a rudimentary shell in Dendronotus, but the presence of other organs, including the rasping-tongue, proves their relationship to the garden-slug.

Nudibranchs deposit their eggs in protected places, fastening them with mucus against rocks and seaweeds. One may recognize the egg-mass of Dendronotus by its salmon-pink color and its coiled arrangement.

The color of this animal is rich brown; the same colors occur in its immediate environment. Quite as valuable as the color-resemblance, in protecting the nudibranch against ravenous fish, is the marked similarity of the cerata, in form, to the delicate branches of certain seaweeds. The slowness of the animal's movements must also aid it in escaping notice.

Definition of Gasteropoda (Gr. *gaster*, stomach; *pous* (*pod*), foot). The class represented by the snails, the slug, and the nudibranch is given the name *Gasterop'oda.* The class-name is only figuratively correct. The ventral surface, not the stomach, is modified to form a locomotor organ, the foot.

An important characteristic of the Gasteropoda is the unsymmetrical arrangement of organs. With the exception of the mouth and the opening of the mucus-gland, all the openings of the body are on the right side, even in cases like the slug and nudibranch, where the general form of the body is bilaterally symmetrical. The asymmetry (lack of symmetry) of the organs is directly connected with the existence (present or past) of a shell. When a shell occurs it is composed of one piece, and the characteristic form is spiral. A shell-forming organ, the mantle, is usually present.

The body of Gasteropoda is not divided into somites, but the head is slightly marked off from the rest of the animal, and is provided with eyes and unsegmented tentacles. A tongue-like organ bears a ribbon of minute teeth for tearing food.

The Squid. In the waters of the Grand Banks of Newfoundland and southward to Massachusetts the members of a species of squid, *Ommas'trephes illecebro'sa* (Fig. 96), occur in great numbers. They capture small fishes, and are themselves prey for cod and other large fishes.

The body of the squid is composed of a head and a slender, conical portion, the former having a pair of large, movable eyes (Fig. 96, 6). Arising from the head-region are ten long, club-shaped arms (Fig. 96, 1), corresponding morphologically to the foot of the Pelecypoda and the Gasteropoda. Two of the arms are longer than the other eight, but all are provided on part of the inner surface with many sucking-disks, adapted to holding the prey. The mouth has two horny jaws, resembling in appearance the bill of a parrot turned upside down. The tongue is adapted to rasping.

The conical portion of the body is the mantle (Fig. 96, 2), highly modified by the existence of strong, muscular bands. Part of the space within the muscular mantle is occupied by the internal organs inclosed in a body-cavity. The remainder of the space, the mantle-cavity itself, connects with the outside by a narrow opening (Fig. 96, 5), at either side of the neck, and also by the siphon (Fig. 96, 4). A pair of feather-shaped gills, one attached to either side of the body, lies in the mantle-cavity. Imbedded in the tissue of the mantle, on the side opposite the surface shown in the figure, there is a long, pen-shaped structure composed of chitinous material. This is supposed to be the homologue of the shell of Pelecypoda and Gasteropoda. The sexes are separate.

In locomotion the squid contracts and relaxes the circular muscles of the mantle, alternately decreasing and increasing the volume of the mantle-cavity. During relaxation, water enters the mantle-cavity at the sides by the neck, a valve in the siphon being closed; in contraction the valves at the side openings are closed and the water is discharged

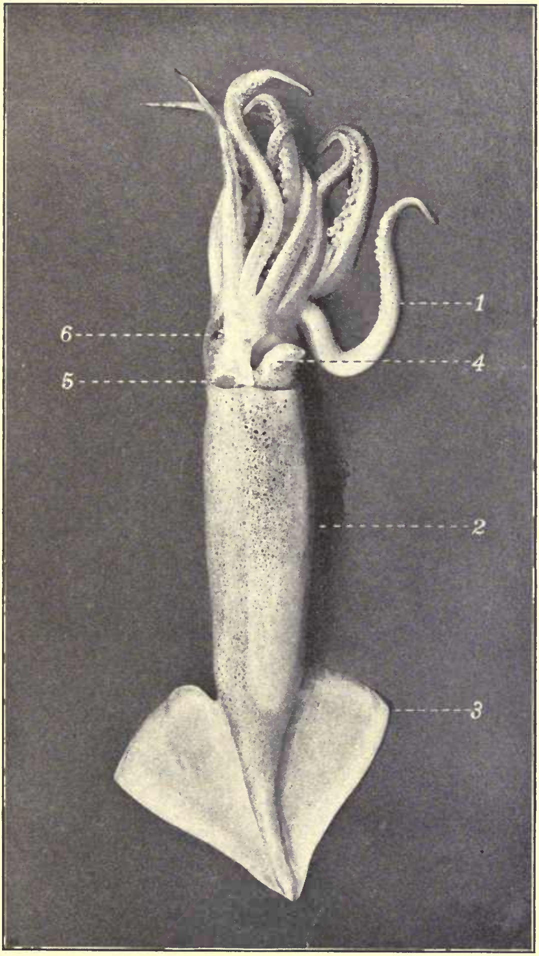


FIG. 96. Photograph of Squid. × $\frac{1}{3}$

1, tentacle; 2, mantle; 3, mantle-fin; 4, siphon; 5, incurrent opening; 6, eye through the siphon. The siphon may be directed forward or backward at will. If it is bent in the direction of the arms, as it commonly is, the squid during strong contraction of the mantle darts backward "with the speed of an arrow," balanced and steered by the aid of the double mantle-fin (Fig. 96, 3).

In the squid's most rapid locomotion the mantle-fins are folded toward the body. In slower movements a wave-like flapping of the fins supplements the jets from the siphon. So skillfully manipulated are the mantle-fins, and the mantle-point itself, in turning to one side or the other, and in going up or down, that one marvels at the wonderful adaptations of an animal that has its "steering-gear" in front, instead of behind, its principal "engine."

While at rest on the bottom of an aquarium the squid extends its two long arms to the bottom, bent akimbo, apparently to keep the siphon and the two lateral mantle-openings away from the sand. The mantle forms the third point of support in the resting attitude. Water may then be drawn into the mantle-cavity, and expelled again, in the normal process of respiration.

No more beautiful example of rapid color-change can be witnessed than the one going on constantly in the skin of captive squids. From bluish white the color may change on the instant to mottled red or brown. The change may be sudden and complete, or the colors may fluctuate repeatedly from one shade to another and shimmer over the surface seemingly as rapidly as the controlling nerves can act. Observers who have been fortunate enough to come upon a "school" of squids in a harbor have been puzzled by the sudden disappearance of the animals. In times of danger the ability to change color to resemble the environment must be of considerable value to them in escaping the notice of enemies, as well as useful in coming unseen into a school of small fish.

Another and still more effective means of escaping from the attack of a superior enemy is employed by the squid when driven to its last resource. It has in its body-cavity a sac which secretes a black, inky fluid. A tube from the ink-sac passes to the siphon, and in the moment of need the sac and the muscular mantle contract and force the black, confusing fluid into the water. The squid then has a chance to escape.

The Chambered Nautilus. Almost the sole representative of a once numerous race living in the depths of the sea, the chambered or pearly nautilus (*Nau'tilus pompil'ius*, Fig. 97) now has a restricted distribution in the vicinity of certain South Pacific islands, such as New Guinea and the Philippines. Nautilus lives on the bottom, usually in water from one hundred to seven hundred meters deep (three hundred and twenty-five to twenty-three hundred feet).

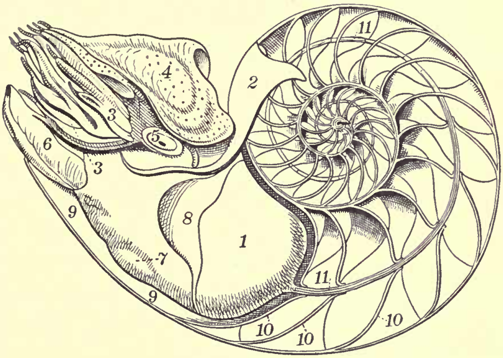


Fig. 97. Nautilus. Reduced. (After Ludwig)

1, mantle; 2, dorsal fold of mantle; 3, tentacles; 4, head-fold; 5, eye; 6, siphon; 7, position of nidamental gland; 8, shell-muscle; 9, living chamber; 10, partitions between chambers; 11, siphuncle with tube

(From Hertwig-Kingsley's *General Zoölogy*)

The shell of Nautilus is divided into compartments by cross-partitions. Each of these compartments represents a space in which the animal lived at successive stages in its growth. The chambers of the entire series are filled with air and are connected by a slender tube called the *siphuncle*, borne in a thin-walled, calcareous tube (Fig. 97, 11). The siphuncle is a part of the animal's body proper. A mantle lies within the outermost chamber of the shell and extends a dorsal fold outward against the old part of the shell. When the animal is contracted into the outer chamber a thick brown hood conceals it from view. When the head is extended two large eyes, about forty tentacles (arms), and a siphon are visible. The mouth is provided with a beak like that of the squid, and with a rasping-tongue. Inside the mantle-cavity there are four gills. There is no ink-sac. Another difference between the chambered nautilus and the squid is the entire absence in the former of the ability to change color. The sexes are separate, as in the squid.

The food of the animal consists of deep-water bivalves. In obtaining food Nautilus probably uses the tentacles. Although these organs have no sucking-disks, as the squid has, the inner edges of the tentacles appear to have the power of flattening against an object and of holding it effectively.

Owing to the fact that Nautilus lives at great depths, we know very little concerning its habits. Professor Willey, of England, and Professor Dean, of Columbia University, have studied the live Nautilus recently (1895 to 1901), and have published reports on that subject. Nautilus is accustomed to a great pressure of water and low temperature. When brought to the surface in traps it could scarcely be expected to act naturally. However, it seems reasonable to believe that the method of locomotion would not be affected. It swims by means of a jet of water from the siphon, and the convex surface of the shell parts the water in its progress.

Oliver Wendell Holmes, in his poem, *The Chambered Nautilus*, thus refers to the phenomena of its growth:

> Year after year beheld the silent toil
> That spread his lustrous coil;
> Still, as the spiral grew,
> He left the past year's dwelling for the new,
> Stole with soft step its shining archway through,
> Built up its idle door,
> Stretched in his last-found home and knew the old no more.

Fossil Relatives of Nautilus. Many millions of years ago, in the early history of the earth, the most ancient of the immediate ancestors of Nautilus lived. Paleontologists (students of fossils) have given its fossil (Fig. 98) the name *Orthoc'eras* (Gr. *orthos*, straight; *keras*, horn). The strongest evidence we have that Orthoceras is a relative of Nautilus is the series of chambers joined by the siphuncle. We know nothing of the structure of the soft parts of Orthoceras, but paleontologists have made drawings to show how Orthoceras probably appeared. From the study of fossils in later layers of the earth's crust we know that the group of nautiloids (Nautilus-like animals) grew to be of large size, and to have their shells coiled more and more to the close coil of the present-day Nautilus. All of the hundreds of species of nautiloids, except four species of Nautilus, disappeared as living things ages before man came into existence upon the earth.

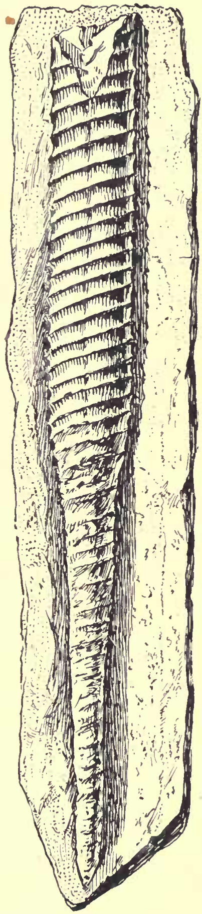


FIG. 98. Fossil Orthoceras. Reduced. (After Blake)

Definition of Cephalopoda (Gr. *kephale*, head; *pous* (*pod*), foot). Ommastrephes, Nautilus, and Orthoceras, because of their structural relationship, belong in a class together, the *Cephalop'oda*.

In this class the body has a distinct head. No part shows indications of being divided into somites. The head has two large eyes. The mouth is surrounded by divisions of the primitive foot, called arms or tentacles. These divisions of the foot either have sucking-disks for holding on, or smooth surfaces which perform the same function. In the mouth there is a parrot-like beak and a rasping-tongue. A shell-forming mantle either incloses the shell, as in the squid, or lies beneath it, as in Nautilus and Orthoceras.

There are two gills in the mantle-cavity in the squid, and four in Nautilus. A siphon is present in all the examples described. The sexes are separate.

Definition of Mollusca (Lat. *molluscus*, soft). The phylum *Mollus'ca* includes five classes. For the purpose of elementary study the most important ones are the Pelecypoda, the Gasteropoda, and the Cephalopoda.

On the basis of the facts presented in this and the preceding chapter, we may formulate the following statement concerning the phylum. Mollusca are soft-bodied animals provided usually with a hard, calcareous, partly chitinous shell, which in some forms occurs on the exterior, and in others is partially or completely inclosed by a sheet of shell-forming muscular tissue, the mantle. The body proper is never divided into somites, and the appendages are never segmented.

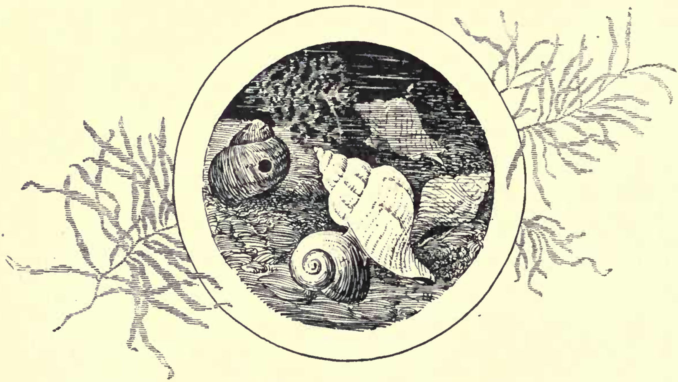


Fig. 99. Living Oyster-Drill and Periwinkle. $\times \frac{2}{3}$

CHAPTER XVI

THE EARTHWORM

I guess the pussy-willows now
Are creeping out on every bough
    Along the brook; and robins look
For early worms behind the plough.

HENRY VAN DYKE, *An Angler's Wish.*

Habitat and Distribution. The animal which is the subject of this chapter is distributed widely throughout the world. The more familiar species live in the soil, where their burrows extend obliquely downward, sometimes many feet. One rather common species, *Allolobоph'ora fœ'tida*, marked by red and dark bands of color, lives in manure heaps. When irritated it gives off an offensive odor, whence its specific name. The species best known in America is *Lumbri'cus terres'tris.* It is found in small cylindrical burrows, which it makes in the soil wherever it is not too dry or too sandy. In spite of the usual habit of living in the earth, these animals can live for many days in a body of water without great discomfort. Representatives of the many species and the few genera of earthworms are found in practically all places from Arctic to Antarctic regions, including isolated oceanic islands.

External Structure. In external structure the body of the earthworm is very simple. The anterior end is slender and pointed when extended in life, and the posterior region is flattened above as well as below. The *somites* of the anterior region differ also from those in the posterior region in being longer. There is no head, no thorax, and no abdomen. There are no appendages except *bristles*, almost microscopic in size, which occur in rows on the ventral surface of every somite except a few at the anterior end. The openings of the body are the *mouth* at the anterior end just beneath the *prostomium* (lip), the *anus* at the posterior end, and various openings on the ventral surface, which are connected with internal organs to be described later. The earthworm has no eyes, yet it knows of the existence of light, and shuns intense light; it has no ears, but it becomes aware of the approach of an enemy by the jar communicated through the soil. In the mature earthworm a thick band, consisting of the thickened body-wall, is visible at about one third the length of the animal from the anterior end. This is called the *clitellum.*

Physiological Processes

The internal anatomy of the earthworm seems, on reference to Fig. 100, to be very complicated, but we shall find that each system of organs has well-defined uses. From the study of the internal organs represented here we shall learn something of the uses of internal organs in general; and we shall endeavor to understand more fully the nature of *physiological processes*, which have been briefly referred to in the chapter on the locust. We have already become familiar with the organs in which these processes take place under the names digestive system, circulatory system, respiratory system, excretory system, and the like.

Digestion. The first division of the digestive system of the earthworm is the *mouth* (Fig. 100, 6), followed by the *pharynx* (Fig. 100, 7), the latter having a very thick muscular wall. The pharynx can be protruded slightly or retracted, and the cavity enlarged by strands of muscle-fibers which extend to the body-wall (Fig. 100, 9). Food, consisting of particles of leaves, animal tissues, and even soil, is drawn into the pharynx by the sucking action which takes place when the cavity of the pharynx is enlarged. The food passes directly through

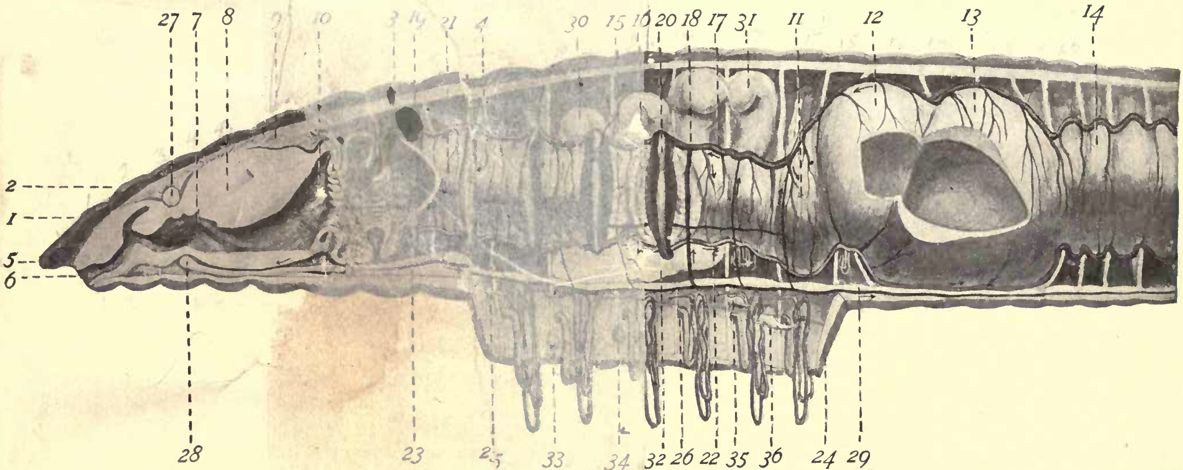


FIG. 100. Dissection of the Earthworm (*Lumbricus terrestris*). × 4. (Lateral blood-vessels and connections, after Johnston)

1, first somite; 2, second somite; 3, seventh somite; 4, septum; 5, prostomium; 6, mouth; 7, pharynx; 8, wall of pharynx; 9, retractor muscle of pharynx; 10, beginning of œsophagus; 11, end of œsophagus; 12, crop; 13, gizzard; 14, intestine; 15, anterior calciferous gland; 16, middle calciferous gland; 17, dorsal blood-vessel; 18, parietal blood-vessel; 19, first heart; 20, fifth heart; 21, lateral blood-vessel; 22, ventral blood-vessel; 23, subneural blood-vessel; 24, body-wall; 25, internal end of nephridium; 26, external end of nephridium; 27, supraœsophageal ganglion; 28, subœsophageal ganglion; 29, ventral nerve-chain; 30, anterior seminal vesicle; 31, posterior seminal vesicle; 32, basal portion of seminal vesicle; 33, anterior seminal receptacle; 34, posterior seminal receptacle; 35, ovary; 36, oviduct the *œsophagus* (Fig. 100, 10, 11). Before the ingested (swallowed) food reaches the *crop* (Fig. 100, 12) the secretion, and sometimes even hard particles from the *calciferous glands* (Fig. 100, 15, 16), mixes with it and probably serves to neutralize whatever acid may be present, and helps to maintain the contents of the œsophagus in an alkaline condition, so that the digestive fluid of the *intestine* (Fig. 100, 14), which is alkaline in chemical nature, can act without interference. The crop is a temporary reservoir for the food, and the *gizzard* (Fig. 100, 13) is the only place in the entire digestive system adapted for dividing large particles of food into minute pieces. Earthworms are known to swallow small, rough pebbles, and even sharp pieces of glass, for the purpose of using them in the gizzard to grind into bits other particles which are swallowed as food. The strong muscles in the wall of the gizzard, by contracting, grind the contents together, and every particle is worn smaller.

The process of digestion in the earthworm begins when, on seizing food with its lip, the animal pours out a secretion from glands in the pharynx. Digestion continues as the food is being drawn into the pharynx, and while on its way through the œsophagus. Experiments with the digestive fluid of earthworms indicate that it has a chemical action on the three principal classes of organic foods, namely, *proteids*, *carbohydrates*, and *fats*. The proteids which the earthworm would be likely to devour are bits of muscle of very small animals, and protoplasm, the living cell-substance of both animals and plants. The carbohydrates, such as the starch-granules or the sugar of any vegetable cell, form a large portion of its food, while fats are eaten probably in small quantities.

The digestive fluid of the earthworm resembles the digestive fluid of the higher animals, not only in being capable of acting on the three important classes of organic foods, but also in containing some of the same special chemical compounds which have the digestive action. These are called *ferments*, or *enzymes*. The peculiar quality of an enzyme is to cause a chemical change in another substance without itself losing any of its own properties. Thus, *trypsin*, the enzyme which acts on proteids, can do so and still remain trypsin. Similarly, the enzyme *diastase* acts upon starch, and *steapsin* upon fats.

Let us consider for a moment why it is necessary for the earthworm, or any animal, to secrete elaborate chemical mixtures like digestive fluids. If we were to examine the alimentary canal of the earthworm, we should find that there are no openings leading from the canal to the body-cavity which might permit food to pass directly to different organs. The wall of the canal is thin, but it is made of cells which are packed closely together. Water will pass through this membrane easily, but certain other substances, although in a liquid state, will not pass through so readily. Those solutions which pass through an animal-membrane readily are called *crystalloids;* for example, solutions of salt or sugar. Liquids which do not pass readily through an animal-membrane are known as *colloids;* for example, solutions of meat-juice or starch. The action of the digestive fluid is a double one: it changes the state of the solid food *physically*, by rendering it liquid ; it changes the state of organic foods (both solid and liquid) *chemically*, giving at the same time to each of the altered food-substances a new physical property, namely, that of being able to pass through the intestine-wall.

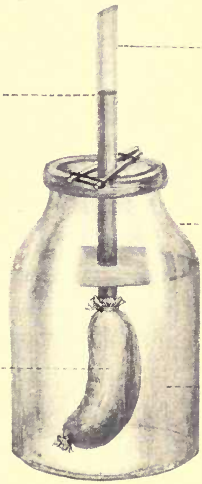


FIG. 101. Experiment showing Osmosis

1, bottle; 2, water; 3, tube; 4, piece of sheep's intestine containing salt-solution; 5, level of salt-solution

For illustration, we may suppose that an earthworm has swallowed a small piece of potato which contains a great deal of starch. In the intestine the starch is changed physically by being made liquid or partially so, and it is changed chemically by the enzyme diastase into a sugar-compound. In the latter state, what was once starch passes readily through the wall of the intestine. A proteid substance like meat-juice cannot pass, except in a slight degree, through the intestine until it has been changed chemically; this is done by the enzyme trypsin. The changed substance is called a *peptone*. It is not likely that earthworms in nature ever need to digest considerable quantities of fat, but in experiments fats have been fed to earthworms. Results followed similar to those obtained in many other animals which usually consume fats. The enzyme steapsin separates the fats into compounds known as *glycerin* and *fatty acid*. The fatty acids combine chemically with the alkali in the digestive tract, resulting in compounds similar to soap; the process is therefore called *saponification*. When the proteids are changed to peptones, the starch to sugar, and the fats to glycerin and soaps, then these organic foods are ready to pass with any inorganic foods, — as, for example, salt and water, — through the wall of the intestine.

Absorption. Digested food passes through the intestine-wall and mixes with the body-fluids, in accordance with a principle known in physics as *osmosis* (see Fig. 101). In the experiment illustrated in the figure there is a salt-solution in the sac made of sheep's intestine (Fig. 101, 4), and pure water in the beaker outside. The experiment is supposed to have been started with the salt water and the pure water at the same level. Within a half-hour the level of the salt-solution has risen several inches. Besides, some of the salt-solution has passed through the membrane into the pure water. It is one of the phenomena of osmosis that a greater amount of liquid passes from the less dense to the more dense solution than in the contrary direction. If the pure water in the experiment were replaced by a colloid-solution, then the passage of liquid would practically all be from the salt-solution into the colloid-solution.

It is well known that a crystalloid, like salt or sugar, if placed in a vessel of water, will soon diffuse through the water. In doing so it exerts a certain amount of pressure. This is called osmotic pressure. If a permeable membrane be interposed between a solution of crystalloids and one of colloids, both substances will exert some osmotic pressure, but by far the greater amount is exerted by the crystalloid, because of its greater facility in diffusing through water. Applying the principle of osmosis to absorption in the intestine of the earthworm, we have crystalloids in the cavity of the intestine, a permeable though not porous membrane (the intestine-wall), and colloids in the blood and body-cavity fluid. The digested food diffuses through the intestine-wall because of the pressure it exerts in seeking to mix with more water. Food on passing to the blood is changed by the cells of the intestine-wall from the crystalloid condition to a colloid, and is henceforth incapable of passing back through the membrane.

Circulation. Whenever an animal body is too large or complicated for the food to reach all the cells directly, we find a circulatory system developed. The circulatory system of the earthworm is complete, and rather complex. The *dorsal blood-vessel* (Fig. 100, 17) extends the length of the animal, along the middle, between the body-wall and the alimentary canal. The blood flows toward the anterior region in somewhat regular "pulses," carried along by waves of muscular contraction in the wall of the blood-vessel itself. Between the pharynx and the crop are situated five pairs of "hearts" (Fig. 100, 19, 20). These short tubes receive most of the blood that comes forward, take up the waves of contraction sent along the dorsal vessel, and force the blood into the *ventral blood-vessel* (Fig. 100, 22), which carries it posteriorly in a regular flow. Below the ventral nerve-chain is the *subneural blood-vessel* (Fig. 100, 23), in which the blood probably flows backward. The *lateral blood-vessel* (Fig. 100, 21), with its connections, is limited to the region anterior to the crop. *Capillaries* (fine blood-vessels joining larger ones) branch in the wall of the intestine and connect in a very complicated fashion with all the large vessels. Absorbed food passes into the capillaries and is carried with the blood to the larger blood-vessels, to be transported to all parts of the body. All about the intestine, in the hollow spaces of the somites, there is a large quantity of body-cavity fluid, which is very much like the blood in the vessels, except that it is colorless. It is thought that much of the absorbed food mixes with this fluid. The outcome is the same with food carried by the regular circulatory system and with that taken up by the body-cavity fluid.

Assimilation. The food is transported by the blood in the blood-vessels or in the body-cavity to tissues, where some of it is transformed into protoplasm. Just how this is done no one has been able to discover, but it is known that the transforming process, which is called *assimilation*, takes place in tissues which are alive, — for example, muscles and nerves. We know that the building up of new protoplasm takes place in growth, when new cells are formed, and that it is also made necessary on account of the slow and imperceptible destruction of the protoplasm in oxidation (see below).

It will be helpful at this point to know that of all the food taken into the circulatory system of an animal but very little, except during growth, is actually made into protoplasm. The carbohydrates and the fats that are absorbed, and those that are made from proteids by the protoplasm, together with some unassimilated proteids, are destroyed after they have been stored temporarily either in the lining of the body-cavity, in the muscle-cells, or in the fat-cells. Protoplasm itself breaks down, but to a less extent.

First Stage of Respiration. The earthworm has neither gills, tracheæ, nor lungs; still it can breathe quite as perfectly as the animals which possess one or another of those organs. The essential characteristic of a breathing organ is a thin, moist membrane, with thin-walled capillary blood-vessels on one side and air on the other. The outer skin of the earthworm is thin and moist, and just beneath it are capillaries. While in its burrow, or even in water, air comes in contact with the skin, and its most important element, oxygen, passes through and mixes with the blood. The second stage of respiration comes after oxidation, in the series of events here described.

Oxidation. In the circulating blood there is a red-colored substance called *hæmoglobin.* Oxygen combines chemically with this, and the compound goes with the blood until it reaches tissue-cells which have some food stored in them; then the oxygen combines with the food, which may be carbohydrate, fat, or proteid. The chemical union of oxygen with other elements is of the greatest importance in the life of any plant or animal. A simple example of the result of the chemical union of oxygen with another element may be observed in the burning of coal. It is well known that coal is composed chiefly of carbon. When a quantity of coal is heated it begins to unite with oxygen from the air. During this process four phenomena may be observed: first, the quantity of oxygen in the room is reduced; second, the quantity of coal is reduced; third, an invisible gas is formed; and fourth, heat and light are given off.

When oxygen unites chemically with carbon two kinds of gas may be formed, either carbon monoxide or carbon dioxide, or both. The union of a solid element with a gaseous one to form a gaseous compound accounts for the fact that so great a mass of coal disappears in burning, leaving only the mineral ash behind. We call the union of oxygen with another element *oxidation*.

Forms of Energy. It is important to observe that as oxidation takes place heat and light, which are called forms of energy, are given off. Energy — that is, the power to do work — can be transformed from one form to another; for example, the heat derived by oxidizing coal may be transformed into mechanical energy like that of an engine, and the mechanical energy may be changed into electricity, and the electricity into mechanical energy again, or into heat and light. We may regard the energy which is suddenly released upon the oxidation of the carbon in the coal as having been stored there by the sun millions of years ago, when the coal was the growing tissue of a tree. We may borrow from physics two other terms which will help us in getting the notion of the states in which energy may exist. Energy at rest — as, for example, chemical affinity (that is, the readiness of the carbon to combine with oxygen) — is called *potential* energy; energy in action, as heat, light, electricity, and motion, is called *kinetic* energy. As we have already seen, potential energy may become kinetic energy, and kinetic energy may become potential energy.

When the earthworm swallows a bit of leaf which passes through all stages of digestion, absorption, circulation, and food-storing, or assimilation, the form of the bit of leaf is completely lost, and the chemical composition is also changed; but oxidation has not taken place, and hence the potential energy transformed from the kinetic energy of the sun (heat and light) when the leaf grew, remains unchanged until the all-important phenomenon of oxidation occurs.

Carbohydrates, and especially fats, are capable of combining with a relatively large amount of oxygen, because of the small proportion of that element in those compounds, and the large proportion of carbon. Carbohydrates, chiefly glycogen, one of the many kinds of sugar in nature, are frequently made from proteids by the protoplasm in the cells, and are stored in the liver-cells of the higher animals, to be later transported to their muscle-cells and stored in them until needed. In animals that have no liver, as the earthworm, the glycogen is stored in the cells of the lining of the body-cavity, and in the muscles. A French physiologist, Chauveau, believes that "the glycogen incorporated in the muscular tissue puts at the service of the tissue the energy which it needs for its work." This theory is valuable, because it enables us to see how the energy (heat) released by the oxidation of the small particles of glycogen in the muscle-cells may be transformed into muscular energy without loss. Fats, made either from carbohydrates or from proteid food by the protoplasm, or stored directly in cells from the fatty acids absorbed through the intestine, are reserve material, and are capable of supplying energy when there is need of it.

Second Stage of Respiration. When carbohydrates and fats are oxidized the resulting compounds are carbon dioxide and water, as these foods contain only carbon, hydrogen, and oxygen. Proteids are far more complex. All proteids contain at least carbon, hydrogen, nitrogen, oxygen, sulphur, and usually, in addition, phosphorus. When they are oxidized many different compounds result. The best known of these are uric acid, carbon dioxide, and water. All these compounds are wastes. Carbon dioxide, whether derived from carbohydrates, fats, or proteids, makes its way by the blood to the skin-capillaries of the earthworm, and there passes through the moist membrane to the air outside. The first stage of respiration consists of the absorption of oxygen by the blood-vessels of the skin; the second stage is the excretion of carbon dioxide from the same blood-vessels, through the skin. The entire process of respiration consists simply of an exchange of gases through a membrane.

Metabolism. Before discussing the last of the series of physiological processes, it will prove helpful to consider all that has been said as being descriptive of processes that are merely stages of the one great sum-process of living. In scientific terminology we call this sum-process *metabolism.* Considered as a single process, we recognize a series of events during which things are coming into the body. These things are in the course of making up a part of the body of the organism; this is called *constructive metabolism*, *anabolic metabolism*, or simply *anabolism* (Gr. *ana*, up; *ballein*, to throw). Upon the occurrence of oxidation, food stored in the muscle-cells, and protoplasm, when it is oxidized, are broken up and reduced to simpler chemical compounds; this is *destructive metabolism*, *katabolic metabolism*, or *katabolism* (Gr. *kata*, down; *ballein*, to throw). The products of katabolic metabolism are the wastes of the organism. The undigested food and the indigestible substances that pass through the length of the intestine are not considered wastes, — a fact that has already been stated in the chapter on the locust.

Excretion. The last of the stages of metabolism is *excretion.* In the broadest sense of the term excretion includes all those activities which result in ridding the body of wastes. Carbon dioxide is given off only from the skin; water probably in part from the skin; uric acid and water are discharged from pairs of small contorted funnel-shaped tubes in the lateral portions of the cavity of the somites of the earthworm. These excretory organs are called *nephridia* (Fig. 100, 25, 26). They correspond in function to the kidneys of the higher animals. Each nephridium has the mouth of its funnel extending through a *septum* (Fig. 100, 4) into the cavity immediately anterior to the somite which contains the greater portion of the organ. The external opening of a nephridium is on the ventral surface.

The funnel-shaped end of a nephridium is provided with *cilia* (hair-like structures) inside, which wave downward and carry out such liquid waste products as collect in the body-cavity. Blood-vessels, which break up into capillaries in the wall of the nephridium, also carry a certain amount of waste. The excess water and the nitrogenous waste in the blood are separated in these capillaries and go down the tube, to be discharged at the external opening. The body-cavity fluid is filled with small, free-moving cells, called *amœbocytes*. They have the power of changing their form quickly by extending irregular pointed processes from any part of the cell-body. Owing to this power they can inclose any small particle of solid matter. The amœbocytes dissolve solid particles that fall from the superficial cells of the intestine. Frequently they make their way through the entire intestine-wall, and are passed to the exterior with the contents of the alimentary canal, carrying the waste products with them.

Nerve Control. In the preceding paragraphs we have been considering the stages of metabolism, without making any reference to the fact that no activity of internal or external organs could take place in the body of the earthworm if it were not for the controlling influence of the nervous system. Ingestion, digestion, absorption, circulation, respiration, oxidation, and excretion constitute a chain of processes, largely because the nervous system, acting through the system of muscles, especially in the digestive and the circulatory systems, causes them to take place according to a definite plan. In order to understand how the nervous system of the earthworm may act, it will be necessary first to have some knowledge of the structure of its nervous tissue.

The general plan of the nervous system of the earthworm is similar to that of the locust and the crayfish, but less specialization is evident than in either of the other animals. The "brain" (*supraœsophageal ganglion*, Fig. 100, 27) is a simple, very small, bilobed ganglion, joined by connectives to a *subœsophageal ganglion* (Fig. 100, 28); from the latter a pair of connectives extend along the ventral wall of the body-cavity to the posterior end, with a ganglion (Fig. 100, 29) at every somite. The brain and ventral nerve-chain constitute the *central nervous system.* From each ganglion of the ventral chain two pairs of *nerves* run out to the muscles of the body-wall and the internal organs, and one pair begins in the connective near by. The entire set of nerves leaving the central nervous system constitutes the *peripheral* (surface) *nervous system.*

If we were to trace one of the nerves outward from the central nervous system as it penetrates the muscular tissue, we should find that it divides into many very fine fibers. Certain fibers can be traced to the end as they merge their substance with a muscle-fiber. The nerve-fiber that is united to a muscle-fiber (Fig. 102, 9) is a slender portion of a *nerve-cell* (Fig. 102, 8), the nucleus (Fig. 102, 7) of which is in the central nervous system (Fig. 102, 6). Nerve-cells of this type are called *motor nerve-cells.* The fibers of many motor nerve-cells lie parallel in every nerve. Mingled with them is another type of nerve-cell which has its nucleus (Fig. 102, 2) at or near the skin of the animal, and the terminal portion of its principal fiber (Fig. 102, 3, 4, 5) extending into the central nervous system. Cells of this type are called *sensory nerve-cells.*

Reflex Action. In case an object touches one of the fine sensory hairs on the skin (Fig. 102, 1) of an earthworm, a nervous impulse is sent along the sensory fiber to the ventral nerve-chain. There the impulse is transferred to the short branches of motor fibers, and by them ultimately to the principal motor fiber (Fig. 102, 8). When the impulse reaches the end of the nerve-fiber, the muscle-fiber (Fig. 102, 9) to which it is attached contracts. When many sensory nerve-cells are stimulated in this way, many motor cells will carry out the transferred impulse, the muscles will contract, and the animal moves away. This kind of nerve-action is called reflex action because, in a sense, the impulse is reflected back from the ventral nerve-chain.

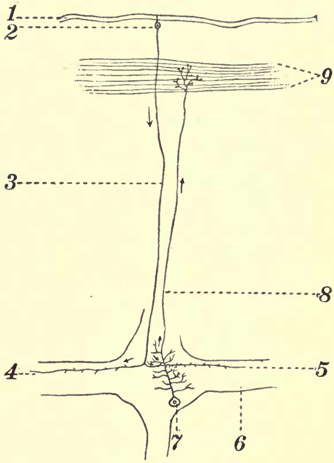


Fig. 102. Reflex Action in the Earthworm. (Reconstructed from drawings by Havet)

(The arrows indicate the path of the nervous impulse)

1, cuticle of skin; 2, sensory nerve-ganglion; 3, sensory nerve-fiber; 4, anterior branch of sensory nerve-fiber; 5, posterior branch of sensory nerve-fiber; 6, ventral nerve-cord; 7, motor nerve-ganglion; 8, motor nerve-fiber; 9, longitudinal muscle-fibers

Reproduction. Every earthworm contains both *spermaries* and *ovaries*. As explained on page 176, animals which have the male and female glands in the same body are called hermaphrodites. There are two pairs of spermaries in the earthworm hidden by the three pairs of *seminal vesicles*, indicated in Fig. 100, 30, 31. The single pair of ovaries (Fig. 100, 35) is very small. Although each earthworm produces spermatozoa and eggs, the eggs of one individual are always fertilized by the spermatozoa of another. During the breeding season, which extends through the greater part of the year, earthworms occasionally meet beneath stones and logs, and affix the ventral surfaces of their bodies together by the anterior thirds pointed in opposite directions, and each expels a quantity of its spermatozoa which are received in cavities of the other, opening from the outside. These cavities (*seminal receptacles*) are four in number, and are in the ninth and tenth somites (Fig. 100, 33, 34). They retain the spermatozoa until the eggs are ready to be laid.

The presence of the thick band, the *clitellum* referred to on page 196, indicates that the individual is sexually mature. The clitellum is provided with glands on its ventral surface. Just preceding the time of egg-laying these glands secrete a thick mucus which forms a ring about the clitellum. Into the space between this ring and the body is poured a milky secretion which is food for the young earthworms. The ring of mucus is then moved forward slowly. At the fourteenth somite the eggs are caught up from the *oviduct* (Fig. 100, 36), which

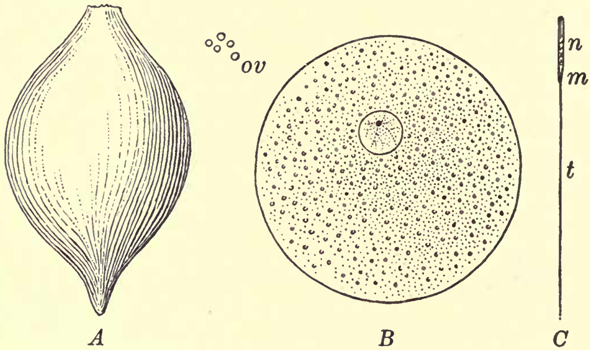


FIG. 103. Egg-capsule, Egg, and Spermatozoön, of Earthworm

A, egg-capsule. *B*, egg with nucleus: *ov*, eggs, about natural size. *C*, spermatozoön: *n*, nucleus; *m*, middle piece; *t*, tail

(From Sedgwick and Wilson's *General Biology*)

forces them out, at the time the ring passes. Farther forward the spermatozoa that have been stored in the seminal receptacles are received into the ring, and while the ring is making its way forward, fertilization, which consists of the union of the spermatozoön with the egg, takes place. At the anterior end the ring begins to draw together at the ends, and when this egg-capsule (Fig. 103, *A*) has been pushed off, it is a short, spindle-shaped, tough-coated sac, about as large as a grain of wheat, inside of which all the eggs are fertilized. Few of them, however, reach the stage of young, free-moving earthworms.

Egg-capsules are found buried in the soil and under stones and boards and other protected places. They are often mistaken for seeds of some plant, which accounts for their identity being unknown to most people.

From the drawing we get an idea of the relative size of the egg (Fig. 103, *B*) and the spermatozoön (Fig. 103, *C*). In the case of animals which produce a large, yolk-filled egg, e.g. birds, the difference in size between the egg and spermatozoön is far greater. The spermatozoön of all animals is microscopic in size.

Maturation. The phenomena of fertilization in the egg of the earthworm are not so well known as they are in a near relative, the sandworm, *Ne'reis* (Fig. 107). The series of figures (Fig. 104, *A*, *B*, *C*, *D*, *E*, *F*, maturation or egg-ripening in Nereis) illustrates in a general way the phases through which the eggs of animals pass before they begin to develop. Fig. 104, *A* shows the egg fully grown and ready to receive the spermatozoön. Among the things to be noted are the egg-membrane and the *nucleus* containing the *germinal spot.* Imbedded in the fine granular protoplasm (*cytoplasm*) about the nucleus are the yolk-granules, destined to nourish the developing embryo, and some large fat-globules.

At about the time of penetration of the egg by the spermatozoön (Fig. 104, *B*) the egg-nucleus begins to lose its outline because of the encroachment of a spindle-shaped structure formed from minute fibers in the cytoplasm. At either pole of the *spindle* is an extremely small granule. These are called *centrosomes* (central bodies). They appear to dominate the formation of the spindle and its movements after formation. The spindle draws from the egg-nucleus a definite number of small, rod-like bodies called *chromosomes* (colored bodies). They are so called because in preparations of thin slices of the egg these little bodies stain in certain dyes more brilliantly than any other part.

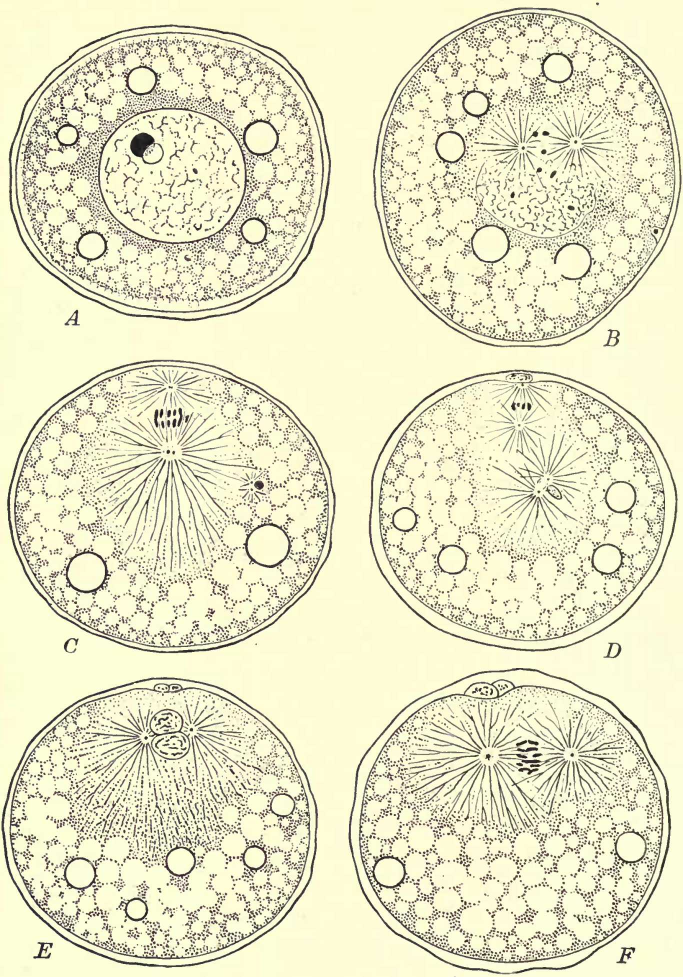


Fig. 104. Maturation and Fertilization in Nereis

A, egg with germinal spot; *B*, egg with first spindle forming, sperm-cell small; *C*, egg with first spindle at periphery, two sperm-centrosomes; *D*, egg with one polar cell formed, spindle with sperm-cell; *E*, egg with second polar cell formed, spindle from sperm-centrosomes; *F*, first cleavage spindle, first stage of embryo

(From Wilson's *The Cell*)

After the chromosomes are arranged across the middle of the spindle, the entire spindle moves end on toward the surface of the egg. As it does so the chromosomes divide each into halves and are drawn to the poles (Fig. 104, *C*). The outer pole makes a prominence on the cell-wall, and soon a little body is formed, the spindle dividing across the middle. We observe that this little body is really a cell, because it has a nucleus with chromosomes, a little cytoplasm, and a wall about it. It is called the *first polar cell.* That portion of the spindle which was left in the egg disappears, but the little centrosome still exists. It soon divides into two, and the parts, gradually separating, form a spindle between them. The chromosomes are again arranged on the spindle. Then the spindle (Fig. 104, *D*) swings around into the plane of the first spindle. As the spindle moves toward the cell-wall again the chromosomes divide as before. A *second polar cell* is formed beneath or slightly to one side of the first. The process of maturation is completed by this phase.

Fertilization. In the eggs of many animals the entrance of the spermatozoön appears to be a stimulus for the beginning of maturation. Whether the spermatozoön enters before or after maturation has begun, it cannot take part in the process of development until the second polar cell has been formed. When this has taken place in Nereis, the egg-spindle and the egg-centrosomes both disappear, leaving the egg-chromosomes inclosed in a nuclear membrane.

The spermatozoön on entering the egg leaves the "tail" outside, its locomotor function being at an end. The "head," which is really the nucleus of the spermatozoön-cell, or sperm-cell as we may now call it, becomes rounded and for a time remains quiescent (Fig. 104, *B*). As indicated in Fig. 104, *C*, the sperm-cell becomes larger, and is drawn toward the central region of the egg by a centrosome, which we shall call the sperm-centrosome, because it came into the egg with the sperm-nucleus. As the sperm-centrosome with its sperm-aster (star-like arrangement of egg-cytoplasm fibers) is drawing the sperm-nucleus inward, division of the centrosome takes place and a spindle begins to form (Fig. 104, *D*). At the same time the sperm-nucleus enlarges to the size of an egg-nucleus. The new spindle with its enlarged sperm-nucleus moves forward until it comes in contact with the egg-nucleus (Fig. 104, *E*), which we remember has lost its centrosome and spindle.

The fibers of the spindle penetrate the nuclear membranes of both egg-nucleus and sperm-nucleus, and drag into the middle plane of the spindle all the chromosomes, the same number from each nucleus. By this act fertilization is completed, and the new individual begins its existence as an *embryo.*

Development. The spindle that is formed at the completion of fertilization is called the *cleavage spindle.* After the chromosomes divide (Fig. 104, *F*), and are drawn toward either pole, the young embryo cleaves or divides through the middle, so that in each cell there is an equal amount of cytoplasm. There is also in each cell a nucleus containing chromosomes, half of which came from the egg-nucleus and half from the sperm-nucleus. Each of the two cells divides again, making four cells. The polar cells disappear after a time.

In the eight-cell stage in the earthworm there is the beginning of a cavity at the center of the small sphere. As the number of cells increases the cavity becomes relatively larger, although the diameter of the hollow sphere is no greater than the diameter of an unfertilized egg. When the cavity reaches its maximum relative size the cells are arranged in a single layer just beneath the original egg-membrane. This is called the *blastula* stage. In this stage, as seen in Fig. 105, *B*, a section through the blastula shows that the upper cells are smaller than the lower cells. The larger cells flatten and soon begin to bend inward, as shown in Fig. 105, *D*. The effect of this is to decrease the blastula cavity and to make another cavity with a wide opening to the outside (Fig. 105, *E*, *F*). This is the *gastrula* (little stomach) stage. It is appropriately called so, because at this time the embryo first begins to take food in the egg-capsule; the food is digested in the cavity formed from the outside. In the gastrula it is possible to distinguish two layers of cells, both of which we know came originally

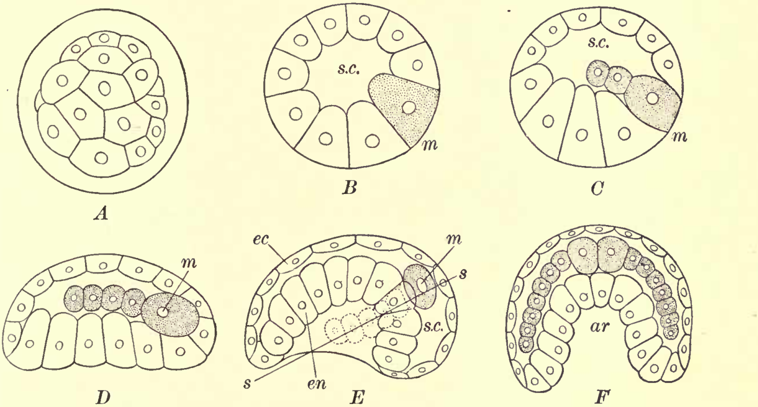


Fig. 105. Early Stages of Development of Earthworm. Much enlarged

A, blastula, surface view. *B*, blastula, section: *s.c.*, blastula cavity; *m*, first cell of mesoderm. *C*, blastula, later stage. *D*, blastula, flattening of future endodermal cells. *E*, gastrula, in side view: *ec*, ectoderm; *en*, endoderm; *s-s*, line of section for *F*. *F*, gastrula, cross section: *ar*, archenteron

(From Sedgwick and Wilson's *General Biology*)

from a single layer; these two layers are called *ectoderm* (Fig. 105, *E*, *ec*) and *endoderm* (Fig. 105, *E*, *en*).

While the embryo is still in the blastula stage a single cell (Fig. 105, *B*, *m*) can be identified as one which later develops into a row of cells on either side, and finally into a mass of tissue on either side, to which we give the name *mesoderm* (Fig. 105, *F*). Many animals pass through these stages; hence the use of the terms ectoderm, endoderm, and mesoderm, as the *primary germ-layers*, has very great significance. Already we can note many changes from the simple blastula condition to the advanced gastrula. In discussing these and subsequent changes, we shall use the word "differentiation," which means literally "a becoming different." Differentiation increases after the gastrula stage, and the embryo becomes longer and larger, as organ after organ makes its appearance out of one or the other of the three germ-layers. However small the organs may be, the trained embryologist knows with a high degree of certainty the origin and history of each one of them.

Before the gastrula has passed into a later stage we can observe in sections cut like those in Figs. 105, *C*, *D*, *E*, *F*, that the two large cells at the closed end of the gastrula, called *pole-cells*, are giving rise by division to a row of mesodermal cells. In the older portion of the two rows of mesodermal cells cavities are beginning to appear (Fig. 106, *A*, *B*). Fig. 106, *B* shows how a gastrula of the same age appears in cross section. Ectoderm and endoderm are separated at the lower portion by a double layer of mesodermal cells, with a small cavity between. The small cavities are the beginnings of the sections of the body-cavity, found complete in the adult earthworm. The cavity at the center of all is the *archenteron* (Fig. 105, *F*, *ar*; Fig. 106, *B*, *ar*), which means old or primitive intestine. The mouth of the gastrula, which is called the *blastopore*, becomes the mouth of the young earthworm. At the opposite point a small opening appears; this becomes the anus of the young animal. Fig. 106, *E*, shows how a longitudinal section through a young earthworm would appear. Development of the embryo to the form of the young is direct.

As the body-cavity increases in relative size the inner layer of cells of the mesoderm becomes applied closely to the wall of the intestine (Fig. 106, *E*, *al*); the outer layer of the mesoderm becomes, from that time on, a part of the outer wall of the body-cavity (Fig. 106, *E*, m^2). Fig. 106, *C*, *D*, *n* illustrates the development of the nervous system out of the ectoderm. The organs and tissues of the earthworm which originate from the germ-layers may be stated briefly as follows. From the ectoderm come the outer skin and the nervous system; from the mesoderm develop the muscles, the blood-vessels, the reproductive organs, and probably the nephridia; from the endoderm comes the lining of the alimentary canal.

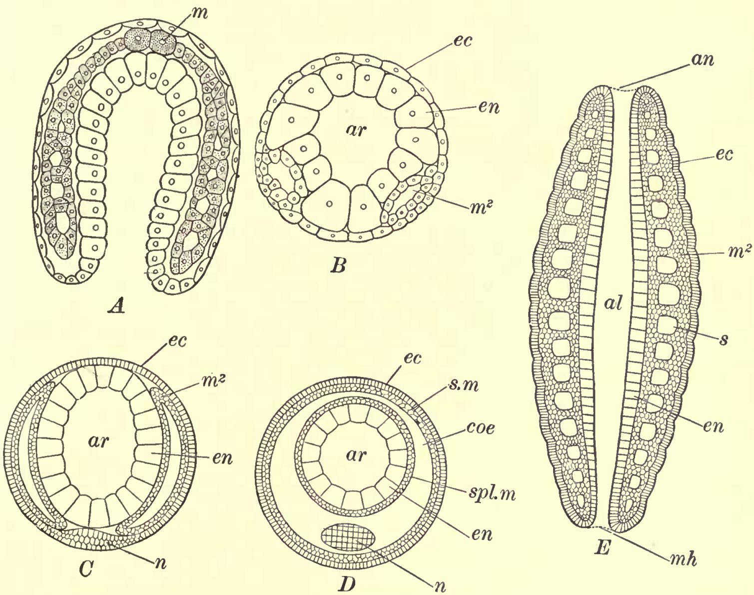


FIG. 106. Late Stages of Development of Earthworm. Much enlarged

A, longitudinal section of gastrula, beginning of portions of body-cavity; *B*, transverse section of gastrula, same stage as *A*; *C*, transverse section of gastrula, body-cavity enlarging, mesoderm divided; *D*, transverse section, inner portion of mesoderm lying against endoderm, outer portion against ectoderm. *E*, longitudinal section of young earthworm, alimentary canal fully formed: *ar*, archenteron; *an*, anus; *al*, alimentary canal; *ec*, ectoderm; *en*, entoderm; *coe*, body-cavity (cœlom); *m*, pole-cells of mesoderm; m^2, mesoderm; *mh*, mouth; *n*, ventral nerve-chain; *s*, cavity of somite; *s.m*, outer layer of mesoderm; *spl. m*, inner layer of mesoderm

(From Sedgwick and Wilson's *General Biology*)

Relation to Environment

We could find no better animal to show how an organism may be adapted to its environment than the earthworm. In the first place, the slender, rounded body with its pointed anterior end is the best possible form for progression through a dense medium, the substance of which is usually displaced by muscular energy. The appendages, which in none of the earthworm's relatives are hard enough to be used for digging, are here reduced to the minimum, only the tips of bristles remaining. The animal is thus not impeded by useless organs. The smooth skin is thin, and is kept moist for use as a breathing-surface. Branched gills, such as are developed on many relatives of the earthworm that live in the sea, would in the earthworm be superfluous, and much in the way. Reasons that explain the presence of eyes in animals which live in the atmosphere, or in the water, lead to the explanation of the absence of eyes in the earthworm.

It is a wonderful fact that the earthworm has no eyes and still is able to distinguish light from darkness; for, except in the time of a rainstorm or in case of disease, it never leaves its burrow in the daytime. By means of the very simple sense-organs in the skin the earthworm can distinguish different intensities of light. It was found recently (1902), during experiments carried on at Harvard University, that earthworms not only appear to know the direction from which light comes, but that they crawl away from light of high intensity and crawl toward light of low intensity. Of course, in the experiment, they did this without reference to the matter of food. In nature, earthworms come out at night, in the warm seasons, probably in response to the stimulus of a low intensity of light, but also for the purpose of obtaining food.

Earthworms are sensitive to changes in temperature, although when in otherwise favorable situations they will endure a rise from 18° C. to 28° C. (64.4° F. to 82.4° F.) without changing their position, — a fact determined by some experiments carried on at Bryn Mawr College. When earthworms rest in the daytime, just below the mouth of their burrows, they do so probably as the result of at least four stimuli, — light, heat, fresh air, and moisture. If certain of these stimuli were taken away, or even changed in degree, the earthworm would undoubtedly move.

For example, if the moisture of the ground should become lessened by continued dry weather, the animal would have to forego the fresh air and retreat in order to prevent its skin from drying, which would shut off respiration altogether. If moisture becomes too great, as in a rain-storm, the burrows are filled with water, and most of the oxygen in the narrow, close quarters is driven out and the rest is soon used up. The earthworm is then compelled, if it has been resting near the surface, to leave its burrow and crawl about. This it may do in protected places without serious results, since the heat at such times cannot have its drying effect on the skin. When the storm is over, those that are not caught up by birds or trampled under foot by large animals can make their way into the soil again. When earthworms are engaged in boring through the soil, the air in their burrows is in circulation, and even though the amount of oxygen may be small, it appears to be sufficient to release the necessary amount of energy for their work.

When animals become adapted in structure and habit to their environment, the result is a definite food-supply and protection to themselves and their race. Certainly the food-supply of earthworms is assured to them, for besides the leaves which they drag into their burrows, they are known to devour the soil itself, taking it into their mouths as they burrow along. Black soil called humus is made up of the usual soil-minerals, mixed with a large amount of decaying vegetable matter and some animal matter. Completely decayed organic matter is that which has returned to its original inorganic, mineral state. The partially decayed organic matter can still be used as tissue-building and energy-producing food; it is this which the earthworms get in the soil they swallow.

It is one of the habits of earthworms to come to the surface at night to void the indigestible contents of the intestine. The coiled, worm-shaped "castings" are familiar to any one who has noticed the ground where the grass is thin, even by the sides of much-used pavements in cities. The soil in the castings is usually brought from depths varying from a very few inches to as great a depth as five feet. Observations made by Darwin, extending over a period of more than forty years, during which time he also collected facts from all parts of the world and published in a book entitled, *The Formation of Vegetable Mould through the Action of Worms*, are extremely valuable to us now, in showing how small agencies acting over wide areas, through ages or even years of time, can yield tremendous results.

If every active earthworm voids its castings at the surface, fallen leaves, sticks, and other bits of organic objects will in a short time be covered with a thin coating of earth brought up from beneath. The humus acids present at all times in the soil attack and disintegrate the organic matter, thus enriching the soil with the minerals which the growth of extensive crops may have deprived it of. Darwin determined the rate at which objects once upon the surface gradually sink to lower depths. Layers of cinders, chalk, stone, etc., were strewn upon small fields, and trenches were dug from year to year to ascertain the progress of the earthworms' activity. In fields of ordinary fertility, having an average supply of worms, the amount of earth brought to the surface and spread out more or less evenly is one fifth of an inch a year. In the course of comparatively few years this is sufficient to conceal from sight objects of considerable size. Indeed, Darwin witnessed a sterile, stony field with flints "as large as a child's head" transformed into a fertile, grass-covered pasture, "so that after thirty years (1871) a horse could gallop over the compact turf from one end of the field to the other, and not strike a single stone with its shoes. This was certainly the work of worms, for, though castings were not frequent for several years, yet some were thrown up month after month, and these gradually increased in numbers as the pasture improved."

Estimates which Darwin based on careful observations indicate that over fifty thousand earthworms find plenty of working-room in an acre of ground, and that these bring to the surface annually from fourteen to eighteen tons of earth.

CHAPTER XVII

ALLIES OF THE EARTHWORM: VERMES

Sinuous, glittering worm of the sea,
Wondrous in sheen of ruby and green.

The Sandworm. One of the commonest of the animals living in the mud and sand at tide-level in protected bays and inlets of all the oceans is the sandworm, known more definitely by its scientific name *Ne'reis vi'rens* (Fig. 107). It lives

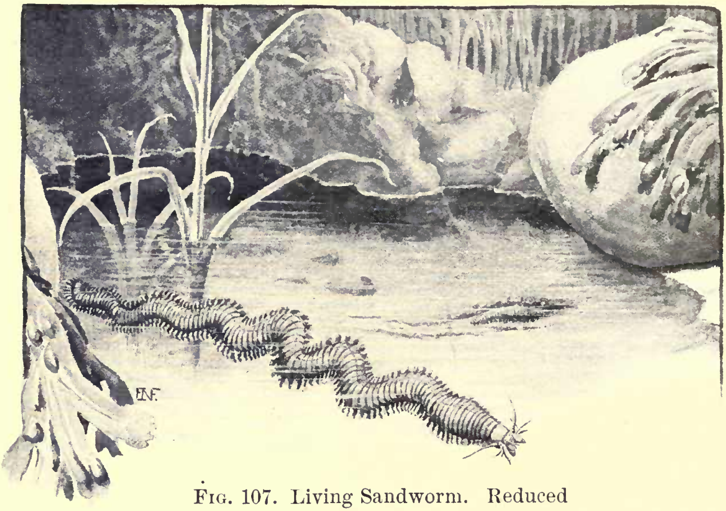


FIG. 107. Living Sandworm. Reduced

in burrows lined with a thick mucus, which unites the grains of sand into a tough, black tube. The depth of these burrows depends on the length of the animal, which is sometimes as great as two feet. Like the earthworm, they often rest with the head near the opening during the day; sometimes at night they leave their burrows to swim at the surface. It is likely, however, that in most cases they do not withdraw the entire body from the burrow, but reach out in all directions for prey that comes near them. When driven from their burrows in the daytime they swim away, and at that time look very beautiful, as the couplet above suggests. Nereis has two horny jaws, sharp-pointed, and bending to meet at the tips. The jaws are concealed by the infolded pharynx when not in use. When about to seize its prey, which consists chiefly of small, live sea-animals, the sandworm suddenly everts the pharynx, and the jaws, thus freed, at once spread horizontally and seize the victim.

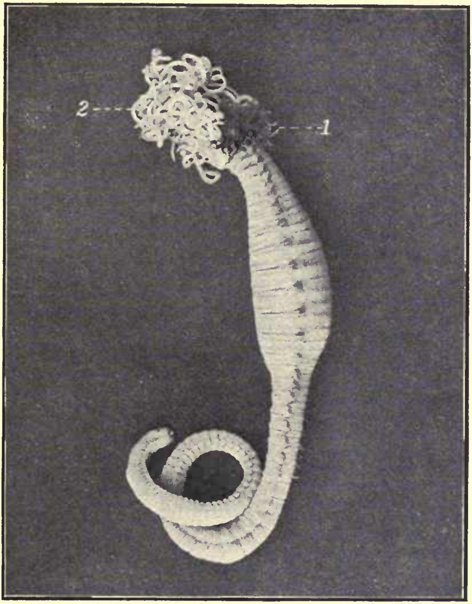


FIG. 108. Photograph of Tube-Worm. Slightly reduced

1, thread-like gills; 2, tentacles

Comparison of the external appearance of the sandworm with that of the earthworm brings out some points of difference, as well as some points of similarity. We observe the same division into somites of approximately uniform structure throughout the body. Fully developed locomotor organs, and a distinct head with eyes and tactile sense-organs, serve to adapt Nereis to the necessities of its environment.

The Tube-Worm. The name "tube-worm" applies equally well to many genera of slender animals that live continuously in tubes of mud, sand, or limy secretions (*Ser'pula*, in Fig. 77) in the sea. In an animal remaining fixed in the sand, like *Amphitri'te orna'ta* (Fig. 108), it would seem to be economy in animal architecture not to have broad swimming appendages like those of its relative, Nereis. On the same principle we observe that gills (Fig. 108, 1) occur only at the anterior end where they may obtain oxygen from the circulating water above the animal. To counterbalance the disadvantage of a fixed habitat, Amphitrite has many long tentacles (Fig. 108, 2) which extend out over an area sometimes of three square feet. These tentacles are covered with scattered fine bristles and with many cilia; the cilia are waving constantly toward the animal's mouth, carrying in the microscopic food present in the water. At the same time the bristles, aided by mucus which is secreted from glands on the tentacles, catch up grains of sand. These are added to the little hummock that conceals the mouth of Amphitrite's permanent home.

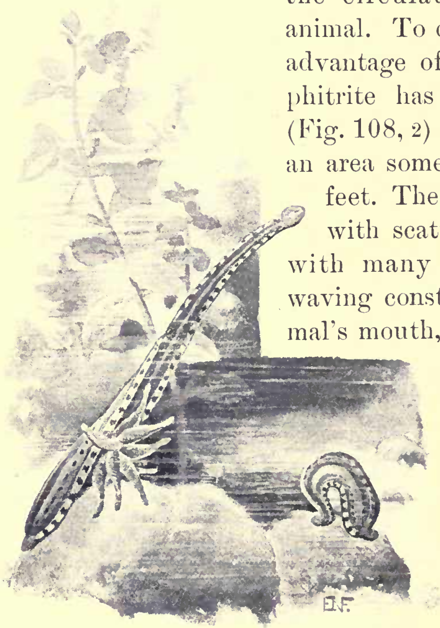


FIG. 109. Leech. Slightly reduced

The Leech. Most species of leeches are known to be temporary parasites on other animals, but *Placobdel'la rugo'sa*

(Fig. 109) feeds on plants that grow among stones and sticks at the bottom of brooks. It is about two inches long and broader near the posterior end than elsewhere. The anterior and posterior sucking-disks on the ventral surface are used for holding on to a support, and for locomotion. Placobdella "loops" itself along, but it cannot swim, as some other species of leech can, although no leeches have appendages.

The body of the leech is divided into thirty-three somites, and these are superficially divided into two and sometimes three rings. Two eyes lie close together on the dorsal surface of the third somite. The mouth is on the ventral surface near the anterior sucking-disk. The pharynx can be rolled out as in Nereis. The color of Placobdella is described by Professor Moore, of the University of Pennsylvania, as a "pepper-and-salt mixture of various light and dark browns, yellows, and greens." Around the margin are light-colored patches.

Leeches are hermaphroditic. Placobdella rugosa carries its eggs in a gelatinous mass on the ventral surface. When the young hatch they live for several weeks attached by the posterior sucker to the parent, as shown in the picture.

Definition of Annulata (Lat. *annulus*, a ring). The earthworm, sandworm, tube-worm, and leech have certain characters in common. The body is divided into somites of nearly uniform shape, the characteristic form being a ring. From that resemblance the name of the phylum *Annula'ta*, also called *Anneli'da*, is derived.

Two classes are represented by these four animals: the *Chætop'oda* (bristle-footed), by Lumbricus, Nereis, and Amphitrite; and the *Hirudin'ea* (Lat. *hirudo*, leech), by Placobdella.

The Flatworm. On the lower surface of submerged stones, near the margin of ponds, there are many little black, or white, flatworms. The most of these belong to a genus called *Plana'ria*. Quite often a larger specimen (10 mm. to 15 mm.) is found among the others. This is most likely to belong to the species *Dendrocœ'lum lac'teum* (Fig. 110). It is nearly colorless except for a clouded middle region. Upon examination with a simple lens an observer may distinguish the organs of the interior with remarkable clearness. The mouth is in the middle of the under surface. It is at the end of a short proboscis (the pharynx) which may be rolled inside out. Microscopic food entering the mouth may pass forward through a slender tube, and into all of the many branches, or it may pass backward by two tubes and into their branches. Since every part of the body has its branch from the digestive tubes, the animal does not need a blood-system. At the anterior end beneath, there is a shallow sucker for holding on to stones or plants. Above there is a pair of small eyes of very simple structure. The body is not divided into somites. Each individual is hermaphroditic.

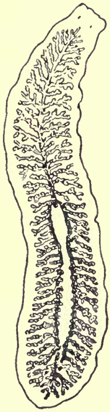


FIG. 110. Flatworm. × 10

The class to which Dendrocœlum lacteum belongs is called *Turbella'ria* (Lat. *turbo*, a whirling, referring to the movement of water about the mouth).

The Trematode. Animals of the appearance of *Dis'tomum somater'iœ* (Fig. 111) are not often seen, because they are parasitic in the bodies of other animals. This species infests the bodies of mussels, and as already stated, is now believed to be the indirect cause of pearls being found in those animals (see p. 174). The figure represents the parasite in a stage which is nearly adult.

The ventral surface of the body has two sucking-disks, one at the anterior end (Fig. 111, 1) and one near the middle (Fig. 111, 5). They are for holding on. The mouth is at the center of the anterior disk, and is connected by a short tube with a wide pharynx (Fig. 111, 2). The gullet is divided into a right and left branch which open into sacs (Fig. 111, 3). Food taken into these sacs passes by osmosis into the tissues. The granular masses (Fig. 111, 4) are the excretory organs. In this stage the ovaries and spermaries are not developed; these organs occur together in each adult. The body is not divided into somites.

The life-history of these parasites is usually very complicated. Professor H. L. Jameson believes that Distomum somateriæ begins its life in a clam found on the coast of France. At a certain stage the young leave the clam and make their way into the mussel, Mytilus edulis (see Fig. 126). The mussels are eaten by the black scoter, a sea-duck, and in the body of the bird the eggs of the parasite are produced and sent out. By some chance the larvæ enter the clam, and thus complete the cycle of development.

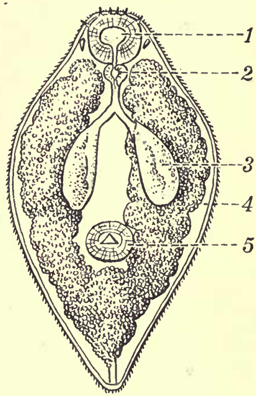


FIG. 111. Trematode. Much enlarged. (After Jameson)

1, anterior sucking-disk, and mouth; 2, pharynx; 3, digestive sac; 4, excretory organs; 5, posterior sucking-disk

The class to which this parasite belongs is called *Trémato'da* (Gr. *trema*, hole; *eidos*, form, referring to appearance of suckers).

The Tapeworm. The best-known tapeworm is the one that is sometimes found to inhabit the intestine of man, *Tæ'nia sagina'ta* (Fig. 112). This parasite frequently grows to the length of many feet. The figure seems to show that the body is divided into somites, but these divisions are not considered true somites. The head of the animal is, except for the narrow neck behind it, the smallest portion of the body; the posterior portion is the oldest part of the parasite, except the head itself. New somite-like divisions of the body form just behind the head, and as they grow older and larger are pushed backward by newer ones. The tapeworm is an interesting example of a parasite that has become so completely dependent on its host that one of the most important systems of the body has totally disappeared, namely the digestive system. The parasite maintains its hold on the inner wall of the intestine by four sucking-disks on the head; the body floats free in the intestine, and food can be absorbed from all sides.

Every tapeworm has in each division both eggs and spermatozoa. The spermatozoa fertilize the eggs in the same division. When the embryos reach a certain stage, a few terminal divisions of the adult separate from the rest, and pass out with the undigested portion of the person's food. Sometimes the embryos, inclosed in their thick membranes, are swallowed by cattle while drinking at pools. In the intestine the membrane of the embryo is dissolved, and the freed larva bores its way through the wall of the intestine, and finally comes to rest in the muscular tissue. It remains there until the muscle is consumed in a partially raw state by man; then in his intestine the young animal develops into the adult, mature tapeworm. Another species of tapeworm (*Tænia so'lium*), found in human beings, comes from uncooked pork.

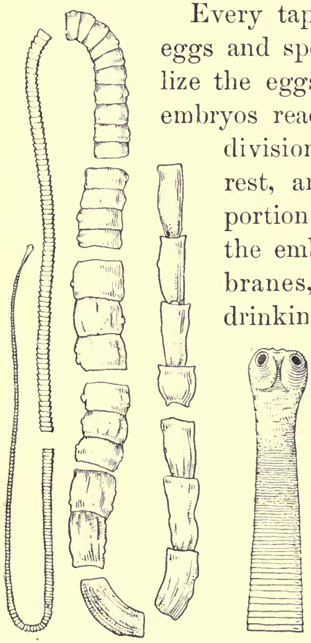


Fig. 112. Tapeworm. Left-hand drawing, reduced; right-hand drawing, enlarged. (After Leuckart)

Tapeworms are not necessarily fatal. The annoyance is considerable, however, until, by a period of fasting and medical treatment, the life of the head of the parasite is destroyed.

The class to which the tapeworms belong is called *Cesto'da* (Gr. *kestos*, girdle; *eidos*, form).

Definition of Platyhelminthes (Gr. *platys*, flat; *helmins*, worm). The three classes, Turbellaria, Trematoda, and Cestoda, constitute the phylum *Platyhelmin'thes.* The members of this phylum are worms with flattened bodies, that are not divided into somites. All the species are hermaphroditic.

Trichina. *Trichi'na spira'lis* (Fig. 113, 1) is one of the most dangerous of parasites. Like the tapeworm it requires two hosts to complete its development. The adult Trichina may be found in the intestine of a pig, rat, or of man. The female Trichina, about 3 mm. ($\frac{1}{8}$ in.) long, brings forth its young alive; the young ones bore their way through the intestine and along the thin connective tissue of the trunk or legs. There they come to rest, and inclose themselves in a thick, tough membrane or cyst (Fig. 113, 2), remaining encysted until the muscle is eaten by another animal. Then the cyst dissolves, permitting the young and still undeveloped Trichina to grow and reach maturity in the intestine of the second host. If the first host is the pig, the second host may be the human being.

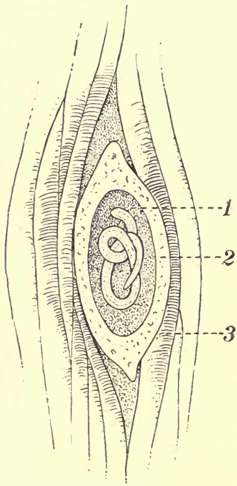


Fig. 113. Trichina. Much enlarged. (After Leuckart)

1, parasite; 2, membrane of cyst; 3, muscle-fiber of pig

The danger to the human being comes while the young are making their way into the muscular tissue. The boring of thousands and sometimes millions of these larval parasites in the muscles disintegrates the tissue and causes a fever, which is very frequently fatal. A simple preventive remedy, which every one should apply, is to see that all pork eaten is well cooked. The Bureau of Animal Industry, United States Department of Agriculture, has officials at all the large packing institutions, who examine microscopically for Trichina and tapeworm larvæ some of the muscle of every animal killed.

Trichina belongs to the class *Nemato'da* (Gr. *nema*, thread; *eidos*, form) and the phylum *Nemathelmin'thes* (Gr. *nema*, thread; *helmins*, worm).

The Rotifer. Sometimes when we examine with the compound microscope the contents of a small drop of stagnant water, we find very small, conical-shaped animals (Fig. 114), with two spines at the end of a short tail, "looping" across the field of vision with considerable vigor. Occasionally they cease the inch-worm method of getting along, and whirl away by means of one or two circular rows of cilia (Fig. 114, 1) at the broad, anterior end. These animals are called rotifers. A common species is *Brachi-o'nus urceola'ris.* In length they are about .3 mm. ($\frac{1}{80}$ in.). Although very small, they possess a complete digestive system, with mouth, pharynx, grinding-apparatus, stomach, digestive gland, intestine and anus, an excretory system (no circulatory system), nervous system, sense-organs, and reproductive system. The individuals are male or female, but the male is to be found only in the fall of the year, and even then rarely. It is about one fourth as large as the female. In some species of rotifers the male is unknown.

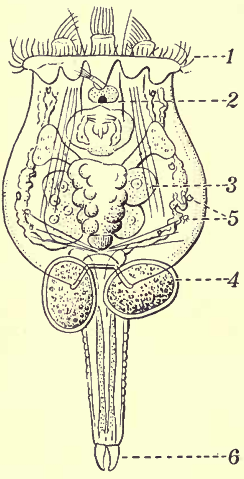


Fig. 114. Rotifer. Much enlarged. (After Weber)

1, cilia; 2, nerve-ganglion; 3, eggs forming; 4, eggs formed; 5, excretory organs, nephridia; 6, terminal spines

There may be more than one generation of females produced in the spring and summer from large eggs, which undergo development while attached near the tail of the parent (Fig. 114, 4). These eggs develop parthenogenetically (see p. 34). The large eggs always produce females. Under certain conditions some small eggs are formed. These develop without fertilization into males. In the autumn the females form "winter eggs," which are fertilized by spermatozoa from the males. The fertilized eggs lie dormant through the winter and develop into females in the spring.

Members of the class to which Brachionus belongs (class *Rotif'era*) are found in bodies of water, both salt and fresh, all over the world. Certain species live in swamps, others at the bottom of deep water, others still at the surface. No matter how great the distance, the same species appears to be present in situations that have approximately identical conditions. This is accounted for partly by the fact that the eggs will endure drying in the mud, and in that condition may be scattered over wide areas by being carried on the feet of birds, or by being blown about by the wind. Thus they have the opportunity of developing in places exactly suited to them. The phylum is called *Trochelmin'thes* (Gr. *trochos*, wheel; *helmins*, worm).

Plumatella. There are many animals which, in their habit of living attached to some object throughout life, resemble plants. Some of them live in a mass composed of many individuals, so closely connected with one another that we give the name "colony" to the entire collection. In the case of *Plumatel'la re'pens* (Fig. 115) the individual zoöids (members of the compound organism) are connected by a system of branching, but the vital organs of each are not connected with those of any other zoöid. A colony of Plumatella grows in a small, roughly branched mass around a dead submerged twig in fresh-water ponds.

Each zoöid is microscopic in size, but, as in the rotifers, we can identify definite and rather highly organized internal organs. The mouth is surrounded by a circle of tentacles that have the function of creating currents in the water, on which food and oxygen are carried to the animal. The circle of tentacles is called the *lophophore* (Fig. 115, 1). From the mouth the food passes by a short gullet (Fig. 115, 3) to the stomach. The intestine is bent on the stomach in such a way that it opens on the exterior (Fig. 115, 4), just outside the circle of tentacles, giving the whole alimentary canal something of the appearance of the letter U. Other organs are a ganglion between the mouth and the anus, a pair of nephridia for excretion, an ovary and a spermary, muscles which withdraw

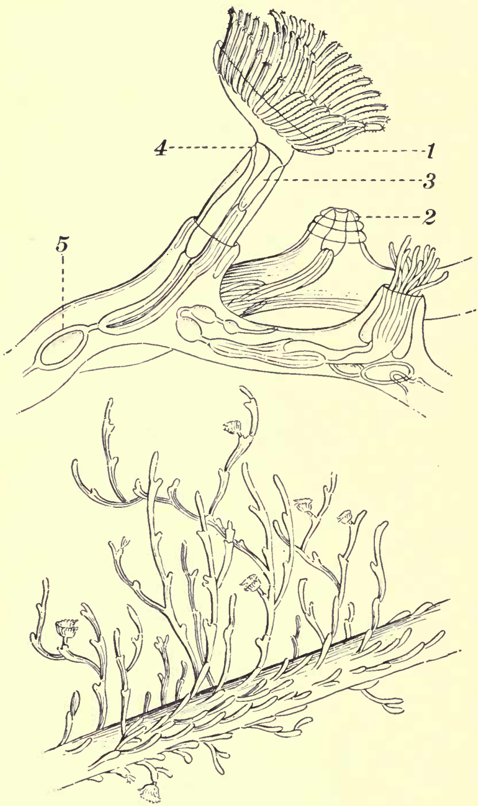


FIG. 115. Plumatella. Upper portion of figure much enlarged; lower portion, slightly enlarged. (After Allman)

1, lophophore; 2, chitinous sheath; 3, gullet; 4, anus; 5, statoblast the body into the chitinous sheath (Fig. 115, 2), and other muscles to extend the body again. Plumatella reproduces by eggs and spermatozoa, by budding, and by *statoblasts* (Fig. 115, 5). Statoblasts are internal buds developed from cells lying upon the retractor muscle, and are covered with a chitinous shell. In case the colony freezes in winter, or the pond dries up, the statoblasts remain alive, and on the return of favorable conditions start a new generation.

The class of which Plumatella is an example is called sometimes *Polyzo'a*, and sometimes *Bryozo'a*. Most of the members of the class live in the sea as mat-like or moss-like fixed colonies. On account of their brownish color and delicate texture some of these colonies are frequently mistaken for brown seaweeds.

The Brachiopod. The first impression that the casual observer has of the animal represented in Fig. 116 (*Lin'gula lepid'ula*) is that he is looking at some kind of a clam, — an impression given by the two calcareous valves which inclose the body proper; but the brachiopod is not a clam. It lives at the bottom of bays, and is found most abundantly in the waters of Japan. It has a shell from one half inch to one inch in length, and a stalk called the *peduncle*, two or three times as long. Professor E. S. Morse, of Salem, Massachusetts, has witnessed the activities of various species of these animals, and has written interestingly of their habits. When undisturbed in a sea-water aquarium, *Glottid'ia pyramida'ta* (Fig. 117) lies with part of its body above the sand. The valves open slightly, and the bristles, extending from between the valves, are grouped roughly into three tubes. The *lophophore* makes a waving motion which sets up currents in the water, as

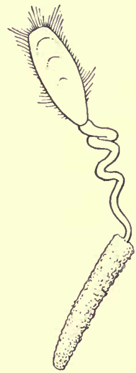


FIG. 116. Brachiopod. Natural size. (After Morse)

shown by the arrows. Through two of these improvised tubes solid (microscopic) food is carried in; through the middle one the unused particles and the excreted wastes of the body are sent away. The bristles are useful in affording a surface for microscopic organisms to grow, which later become food for their larger table-mate; the bristles are also useful in preventing sand from entering the cavity between the valves.

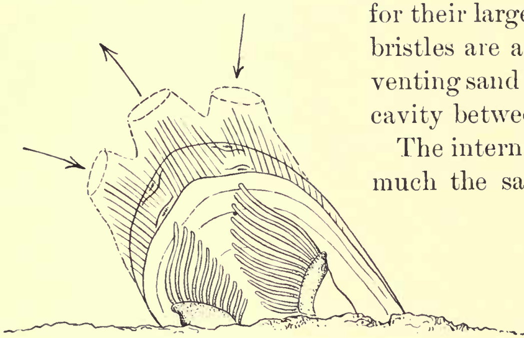


FIG. 117. Brachiopod. Enlarged. (After Morse)

The internal organs are very much the same as in Plumatella. In fact, the nearest living relatives of Lingula and its close allies, the members of the class *Brachiop'oda*, are thought to be the class Polyzoa. Brachiopods are among the oldest of animal groups. The valves of ancient brachiopods found in strata of rock indicate that the class, many millions of years ago, was far more abundant than it is now, and also that the structure of the animals has changed little in all that time.

The phylum represented by Plumatella and Lingula is known by the name *Molluscoi'da*, because of their formerly supposed relationship to the Mollusca.

Definition of Vermes (Lat. *vermis*, a worm). The task of summing up the characteristics of the Arthropoda was a comparatively simple one, but the "worms" comprise such a varied lot of widely different forms, that no important set of structural characteristics can be found that tends to unite them into a clearly defined group. The old systems of classification employed the term "*Ver'mes*" as the name of a subkingdom, to include all those animals that had a long, slender, worm-like form. Many animals that have such a form have been taken out of that branch of the system and placed in another group, because their discovered relationship required it. On the other hand, animals like the brachiopods and the polyzoans were once classed with clams, mussels, and snails, because all possessed a shell; they are now thought to be more nearly related to animals like the earthworm and other annelids than they are to the clams.

So true is it that no single characteristic of structure can be found that tends to unite the organisms classed as worms into a well-defined group, that systematists are accustomed to say that Vermes include all animals that are not clearly members of some other large group. This does not indicate any imperfection in the bodily structure of the members of the group; it means that our knowledge of animal morphology is broken and incomplete, partly from lack of complete investigation, but chiefly because some organisms that must have filled up the "gaps" in the chain of relationships have disappeared entirely, leaving no trace even in fossils. The little basis we have for grouping all the forms discussed in Chapters XVI and XVII into the group Vermes is found in the tendency of the body to show a greater or a less degree of metamerism (division into somites), either in the adult or in the embryo. In these somites the characteristic excretory organ, the nephridium, most highly developed in Nereis and Lumbricus, is nearly always present. In some of the members of the group several pairs of nephridia occur with no other evidence of metamerism. Whenever appendages occur among Vermes they are never jointed, as they are in Arthropoda. Perhaps the strongest indication of relationship existing between widely differing members of the groups, as, for example, Annulata and Molluscoida, is to be found in the great similarity of a certain stage of the free-swimming larvæ of the two phyla.

CHAPTER XVIII

THE STARFISH AND SOME ALLIES: ECHINODERMA

Let the mere star-fish in his vault
  Crawl in a wash of weed, indeed,
Rose-jacynth to the finger-tips.

ROBERT BROWNING.

THE STARFISH

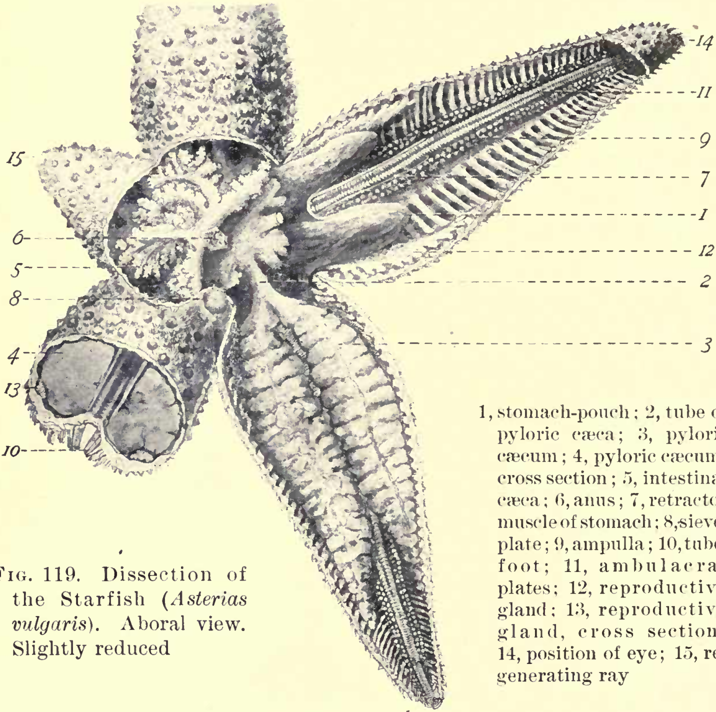
Habitat and Distribution. The purple starfish (*Aste'rias vulga'ris*, Fig. 118) is found most abundantly north of Cape Cod in tide-pools on rocky shores, and in deep water near the shore. It is only in the warmer season, however, that one may witness a scene like that portrayed in the illustration. When the winter storms come on, starfishes and many other tide-pool animals that are not fixed permanently migrate to the deeper water, in order to be in more protected places.

External Structure. Up to this chapter we have been giving our attention to animals that have a perfect, or slightly modified, bilateral symmetry. The starfish evidently has a plan of structure for which we must find some other name. In a specimen we observe five *arms* extending from a central region. The position of the arms with reference to the central region or *disk* is practically the same as the position of radii in a circle. Hence we say that the starfish is *radially symmetrical.* We find it necessary also to change a few terms of location. In the picture of the tide-pool study we are looking down upon the *aboral* surface of the three starfishes. The opposite side has the mouth at the center, and for that reason is called the *oral* surface.

The aboral surface and part of the oral surface of Asterias is thickly set with calcareous *spines* that arise from small

Fig. 118. Tide-Pool Study of Starfishes, East Point, Nahant, Mass.

plates of the same material just within the skin. The spines of the oral surface are longer and more pointed than those of the aboral surface. By examining the aboral spines with a hand-lens one can make out a circle of very minute structures surrounding the base. Each of these structures consists



1, stomach-pouch; 2, tube of pyloric cæca; 3, pyloric cæcum; 4, pyloric cæcum, cross section; 5, intestinal cæca; 6, anus; 7, retractor muscle of stomach; 8, sieve-plate; 9, ampulla; 10, tube-foot; 11, ambulacral plates; 12, reproductive gland; 13, reproductive gland, cross section; 14, position of eye; 15, regenerating ray

FIG. 119. Dissection of the Starfish (*Asterias vulgaris*). Aboral view. Slightly reduced

of a short stalk supporting two branches that open and close like nippers. These short stalks with their branches are called *pedicellariæ*. Their use is unknown, but they may rid the aboral surface of undesirable matter.

Along the middle of the oral surface of each arm there is a groove which begins at the mouth and ends near the tip. The roof of the groove is formed by two series of flat, calcareous plates setting together like the rafters of a frame house. Between the plates four rows of slender, flexible *tube-feet* (Fig. 120, *ab*) extend to the outside. The groove is called the ambulacral groove, because it protects the ambulacral organs (Lat. *ambulare*, to walk). A few of the ambulacral organs (tube-feet) near the tips of the arms are sense-organs for "smelling" food. The remainder are the organs of locomotion. At the very end of each arm there is a small red *eye* protected by a circle of spines.

The Water-Vascular System. On the aboral surface at one of the angles between the arms lies a lens-shaped structure (Fig. 119, 8; Fig. 120, *m*; Fig. 121, 10). This is the *sieve-plate*, sometimes known by the name *madreporic body*. The plate is perforated with fine holes through which sea-water passes to the *stone-canal* (Fig. 120, *s*; Fig. 121, 11). Near the mouth the stone-canal joins the *ring-canal* (Fig. 120, *r*; Fig. 121, 12), which in turn joins five *radial canals* (Fig. 120, *c*; Fig. 121, 13) that extend through the middle of the roof of the ambulacral groove. Many short tubes branch off in pairs from the radial canals and join the tube-feet. At the exposed end of a tube-foot is a *sucking-disk;* at the inner end is a bulb-shaped expansion, the *ampulla* (Fig. 119, 9; Fig. 120, *a*; Fig. 121, 14). From the sieve-plate to the tube-feet there is a continuous cavity, and

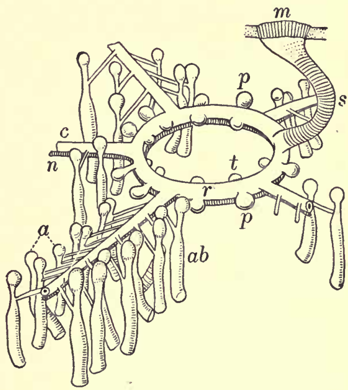


FIG. 120. Ambulacral System of Starfish

a, ampullæ; *ab*, tube-feet; *c*, radial canal; *m*, sieve-plate; *n*, radial nerve; *p*, Polian vesicle; *r*, ring-canal, with nerve-ring beneath; *s*, stone-canal; *t*, Tiedemann's vesicle

(From Hertwig-Kingsley's *Manual of Zoölogy*) because of the fact that water passes through the entire set of tubes it is called the water-vascular system.

This set of organs is a mechanism which enables the starfish to move. The stone-canal being inclosed in a sheath of calcareous substance has a constant diameter, and so have the ring-canal and the radial canals; but the ampullæ and the tube-feet are not inclosed by an unyielding cover, and hence they can increase and decrease the volume of their continuous cavity. Preparation for locomotion is made when the ampulla by contracting causes the water to close a valve at the branch from the radial canal, and then forces the contained water into the cavity of the tube-foot. Simultaneously with the act of forcing water into the tube-feet, circular muscle-fibers in those organs contract and cause the water to extend them to their greatest length. Next, the sucking-disks fasten to some object, it may be even a smooth surface like the glass side of an aquarium tank. The longitudinal muscle-fibers in the tube-feet then contract and drive the contained water back to the ampullæ. When the hundreds of tube-feet in the advancing arms of a starfish are contracting to pull the body along and extending to renew their hold, the arms themselves, turned up a little on the tips, remain in a more or less set attitude, although they may bend now and then to pass an obstruction. When it is necessary the animal can bend its arms and central disk, and pass through seemingly impossible holes.

The Digestive System. The *mouth* (Fig. 121, 1) is a circular opening surrounded by a thin, circular membrane, the *lip*. There is no œsophagus, for the *stomach* (Fig. 121, 2) begins at the mouth and occupies the greater portion of the central disk, besides extending two short pouches (Fig. 119, 1; Fig. 121, 3) into every arm. At the aboral end of the stomach five tubes branch off (Fig. 119, 2; Fig. 121, 5) and are divided again into ten *pyloric cæca* (Fig. 119, 3; Fig. 121, 6). The cavities of these organs are continuous with the cavity of the stomach. The function of the pyloric cæca is digestive; they secrete a fluid analogous to the digestive fluid of the earthworm and the clam. The short *intestine* sends off two branches, which again divide. These branches are called the *intestinal cæca* (Fig. 119, 5; Fig. 121, 7). Their function is to increase the absorbing surface of the intestine. The intestine ends at the *anus* (Fig. 119, 6; Fig. 121, 8), which lies near the center of the aboral surface.

Asterias feeds on oysters, mussels, clams, and snails. Many fanciful theories have been proposed in the effort to explain

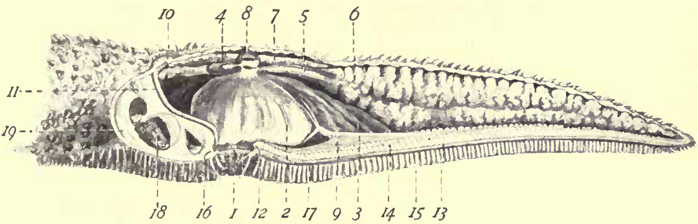


FIG. 121. Dissection of the Starfish (*Asterias vulgaris*), oral-aboral section. Slightly reduced

1, mouth; 2, stomach; 3, stomach-pouch; 4, interradial pouch of intestine; 5, cavity of pyloric cæcum; 6, pyloric cæcum; 7, intestinal cæcum; 8, anus; 9, retractor muscle of stomach; 10, sieve-plate; 11, stone-canal; 12, ring-canal; 13, radial canal; 14, ampulla; 15, tube-foot; 16, nerve-ring; 17, radial nerve; 18, reproductive gland; 19, calcareous plate

how the starfish is able to get at the soft parts of animals with thick, heavy shells. The method employed is totally different from that which any one seems to have imagined before Professor Schiemenz, of Germany, discovered it in 1896. His published results were corroborated by Professor Mead, of Brown University, in 1899. By referring to Fig. 118, at the lower end of the illustration, we can see the attitude of Asterias when it has captured a sea-mussel. While crawling along the bottom the hungry starfish "smells" its prey by means of the tube-feet at the tip of the arms. It then moves in the direction of the mussel and arches itself over the shell, touching the bottom all around with the tips of its arms. Next it turns the mussel about, until the hinge-ligament rests on the bottom and the free edges of the closed valves lie just beneath the captor's mouth. Then the starfish takes a firm hold on the bottom with the tube-feet of the outer portion of its arms, and simultaneously applies the suckers of the remaining tube-feet to both valves of the mussel.

Then the struggle begins. The mussel has long before closed its valves tightly by means of its two strong adductor muscles, and the only way the starfish can get at the soft parts is to force the valves open. This it does by a long-continued, steady pull on the surface of the valves, with two sets of tube-feet drawing in opposite directions. The mussel has great momentary strength, but it seems to be as difficult for it to keep up the strain as it is for a man to hold out his arm several minutes at a time. A single tube-foot of the starfish is very weak, and the combined strength of all its tube-feet measures less than the momentary strength of a mussel. But the starfish can exert much less than its full strength, and open the valves of a mussel within from fifteen to thirty minutes.

As soon as the valves of the mussel are open a few millimeters the starfish contracts certain muscles in its body-cavity, which bring the stomach down toward the oral surface and cause it to pass through the mouth-opening, turning inside out on its way. The everted stomach is applied to the soft body of the mussel, and digestion and absorption begin immediately. With slight variations this is the method which starfishes employ in opening and digesting oysters, snails, and other mollusks.

The Circulatory, Respiratory, and Excretory Systems. The circulatory system is too small to be indicated in drawings on the scale of the dissection drawings. A *circular blood-vessel* lies just below the ring-canal of the water-vascular system, and sends a branch into each arm below the radial canal. The body-cavity is filled with a fluid similar to the blood, which is colorless. The system of blood-vessels is not complete.

The body gets much of the oxygen it needs by way of the water-vascular system. The remainder comes in through the many short-branched *gills*, that cover the aboral surface between the spines like the pile of a soft mat. The gills open into the body-cavity at their bases. Carbon dioxide passes through the same organs which bring in the oxygen.

The diagram shows nine bulb-like organs on the outer margin of the ring-canal. These are called the *Polian vesicles* (Fig. 120, *p*). The small glandular bodies, *Tiedemann's vesicles* (Fig. 120, *t*), which join the Polian vesicles are thought to have the function of producing amœbocyte-cells, described on page 207. The cells on escaping into the body-cavity consume the waste substance of metabolism, and make their way through the body-wall, perishing on the outside. Asterias has no definite organs of excretion, like kidneys or nephridia.

The Nervous System. If an observer takes a live starfish, and parts the tube-feet in an arm so that the animal's skin is exposed between the second and third of the four rows, he may see the dead-white, *radial nerve-cord* extending along just beneath the skin (Fig. 121, 17). Fig. 120 shows the position of the nerve-ring just beneath the ring-canal. The circular blood-vessel lies between the ring-canal and the nerve-ring.

Reproduction and Development. The sexes of Asterias vulgaris are separate, but externally there is no difference between them. At the time the dissections were made for the drawings, the sexual glands in the specimens were small (Fig. 119, 12; Fig. 121, 18). As the first of June approaches, the ten sexual glands increase in size until they occupy all the available space in the body-cavity of the arms. The *ovaries* of the females, when they contain ripe eggs, are bright orange in color; the *spermaries* of the males are light cream color.

From about the first to the middle of July, in the latitude of Boston, the sexual cells are sent out into the water through ten small holes on the aboral surface, two at each angle between the arms all around. The egg-cells are fertilized by the sperm-cells in the water, and within a few hours the young starfish in the *blastula* stage (see p. 214) is swimming about at the surface by the aid of cilia. The manner of development after the *gastrula* stage (see p. 215) is quite different from the plan described for the earthworm. The most striking incident in the development of a starfish is the change that takes place after about three weeks of life as a pelagic bilaterally symmetrical larva, when it settles toward the bottom and fastens temporarily to a seaweed. On the posterior region a star-shaped bud is formed, which becomes the adult starfish. As the bud grows it draws into itself the larva which gave rise to it. The starfish attains the stage of sexual maturity within a year.

Regeneration. It is not unusual to find in a lot of starfishes dredged from the bottom, many specimens that have one or more arms shorter than the others (Fig. 119, 15). This means that some accident has befallen the irregular specimens, and that new arms are being formed to take the place of those that were lost. It has been found that a starfish deprived of all its arms will, under favorable circumstances, reform all five; but one that has suffered an injury as extensive as a cut through the entire disk probably never survives.

The Basket-Fish

Occasionally fishermen bring up on their hooks from the deep waters of sounds specimens of the basket-fish, *Astroph'yton agassiz'ii* (Fig. 122). It is very difficult to keep them alive long on account of the change from the great pressure and the low temperature of their habitat.

The central disk is more distinct in the basket-fish than in the starfish. The five arms, instead of being single, divide and redivide many times. The sieve-plate lies on the oral surface. There is only one opening to the digestive system, the mouth. The tube-feet do not extend to the outside, hence they are not used for locomotion, that activity being accomplished by the branched arms, controlled inside by muscles. Respiration takes place through little pockets which open into the central disk from below.

Only in the rarest instances is it possible to learn anything of the activities of the basket-fish. Mr. A. Agassiz and Mrs. E. C. Agassiz give an interesting account of it in *Seaside*

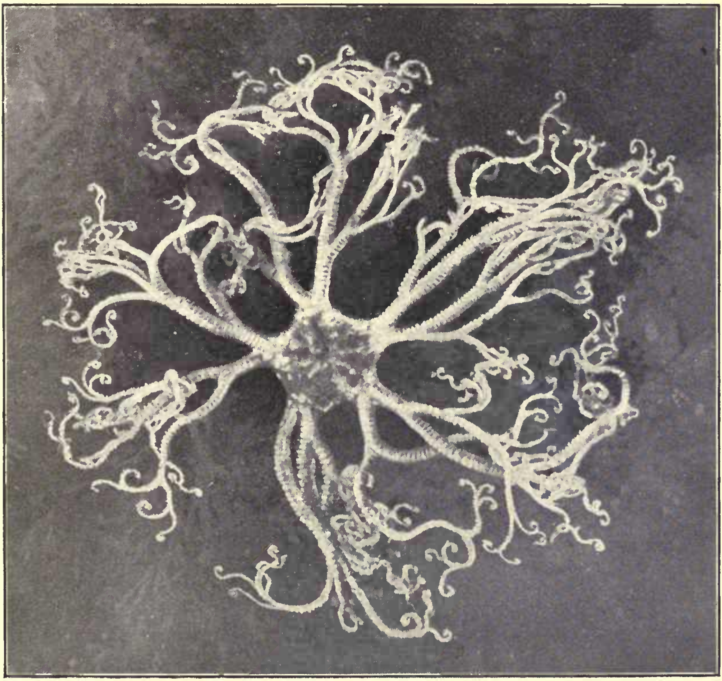


Fig. 122. Photograph of Basket-Fish. × ½

Studies in Natural History. They say: "In moving, the animal lifts itself on the extreme end of these branches, standing, as it were, on tiptoe, so that the ramifications of the arms form a kind of trelliswork all around it, reaching to the ground, while the disk forms a roof. In this living house with latticed walls small fishes and other animals are occasionally seen to take shelter; but woe to the little shrimp or fish who seeks a refuge there, if he be of such a size as to offer his host a tempting mouthful; he will fare as did the fly who accepted the invitation of the spider."

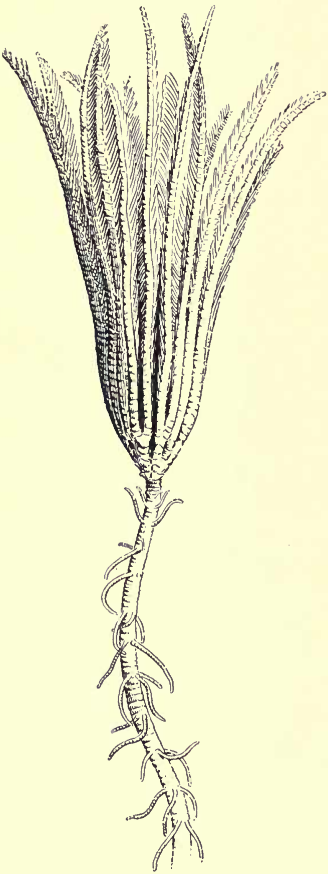


FIG. 123. Sea-Lily. Reduced
(From *Report of H. M. S. Challenger*)

THE SEA-LILY

At the present day we find here and there in the comparatively warm, deep waters of the ocean, animals like that shown in Fig. 123 (*Pentacri'nus bla'kei*). In past geological eras the class to which the sea-lily belongs was far more widely distributed than it is now. Members of the genus Pentacrinus may be obtained by dredging in the deep waters about Porto Rico, and in the South Pacific and the Indian oceans.

The sea-lily is a relative of the starfish and the basket-fish. The central disk and the radial arrangement of the arms make the resemblance striking. In Pentacrinus blakei the number of arms varies; it may be as great as twenty. The sea-lily is different from the starfish and the basket-fish, in having a long stalk which grows from the center of the aboral surface and sends root-like branches in among the rocks at the bottom. The mouth and the arms lie on the oral surface, which is uppermost. A water-vascular system is present, but it is of no service to the animal in locomotion.

Movement in Pentacrinus is limited to the arms. A related genus, *Comat'ulus*, found off the North Atlantic coast, is fixed by a stalk when young, and free in its adult stage, moving about then like a basket-fish. Food is brought to the mouth of Pentacrinus by the wave-like action of cilia on the inner edge of all the arms.

The Sea-Urchin

Practically any tide-pool along the North Atlantic coast that affords specimens of starfish will harbor several sea-urchins. The geographical distribution of the species *Strongylocentro'tus dröbachien'sis* (Fig. 124) is very wide. It is found on the coast of Great Britain and Norway, along the North Atlantic coast, and also on the North Pacific coast, — in all these regions from tide-water down to several hundred fathoms.

Deprived of its spines a sea-urchin suggests, as Professor W. F. Ganong aptly says, "an old-fashioned door-knob." It is flattened on the oral surface and curved above into a rounded dome. From the center of the dome one may trace downward twenty radiating rows of calcareous plates, fitting against one another closely. Five pairs of these plates radiating at equal angles have many fine holes for the tube-feet; five other pairs of plates lie in the spaces between the regions of tube-feet. All over the aboral surface and over most of the oral surface, the plates bear short, rounded knobs on which the spines fit, and form a ball-and-socket joint. On each tube-foot area at the point nearest the center of the aboral surface lies an eye; and between every two eyes there is an opening for the eggs, or spermatozoa, to emerge. A sieve-plate lies in one of the spaces between two eyes. The mouth has five sharp teeth which meet together in a point. The breathing organs are located on the oral surface around the mouth.

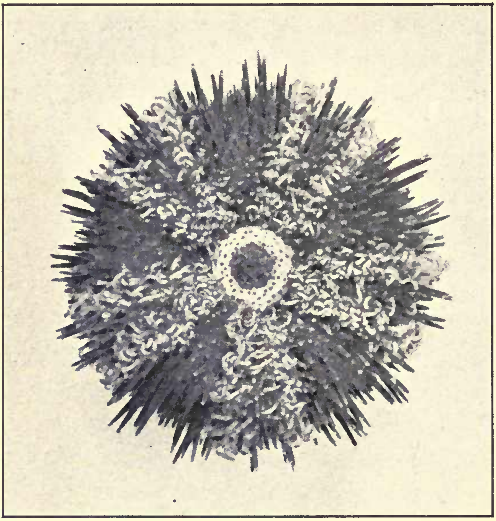


Fig. 124. Photograph of Sea-Urchin. Slightly reduced

Considering the structure of the animal, one could be almost positive that the sea-urchin does not get its food after the manner of the starfish. It feeds on both animal and plant substance. Small animals are captured by the tube-feet. The tube-feet may be extended to a distance equal to half the diameter of the body; they affix by the sucking-disk to some small creature and draw it to the mouth. All food is then ground into bits by the five sharp teeth before being swallowed.

A sea-urchin when taken from the water and placed in a person's hand causes a gentle tickling of the skin. This it does with its movable spines. The spines may be of use as levers in pushing the body along, but locomotion in a definite direction is accomplished by the tube-feet on the oral surface, aided by some of those on the aboral surface, all extending and contracting much as in the starfish. The uppermost tube-feet are used as tentacles for feeling, and it may be for smelling also. The fact that sea-urchins collect in numbers about the body of a large dead animal in the water, indicates that they have the sense of smell.

In certain parts of our eastern coast, members of the genus Strongylocentrotus live in cavities in the rock, which are excavated by the animals themselves. A related species living on the coast of California burrows a hole in the solid rock deep enough to conceal itself entirely. No one knows positively how the burrowing is done. Probably three factors take part to a varying degree, — gnawing by the teeth, slow grinding by voluntary movement of the spines, and incessant slight turnings of the whole body by the waves.

The Sea-Cucumber

Sea-cucumbers of various species are found in every ocean. The species represented in Fig. 125 (*Cucuma'ria chronhjel'mi*) is found in Puget Sound, Washington. It lives on the bottom.

The animals are about four inches long. The body is cylindrical, but without calcareous plates that touch one another and keep the form constant. The only trace of a skeleton comparable to that of the sea-urchin consists of scattered bits of calcareous secretions of definite form beneath the skin. Although the sea-cucumber is radially symmetrical, having the five double rows of tube-feet along the cylinder, we can speak of the anterior and posterior ends, because the animal lies flat.

The anterior region is the oral region. At the center we observe the round mouth, about which are the ten branching tentacles. Internally there is a water-vascular system with a ring-canal and radial canals. In respiration water is drawn into the intestine at the aboral end, and an exchange of gases takes place through internal gills that join the intestine.

The tentacles in the picture are not extended in the usual radial direction. The reason is that when photographed the

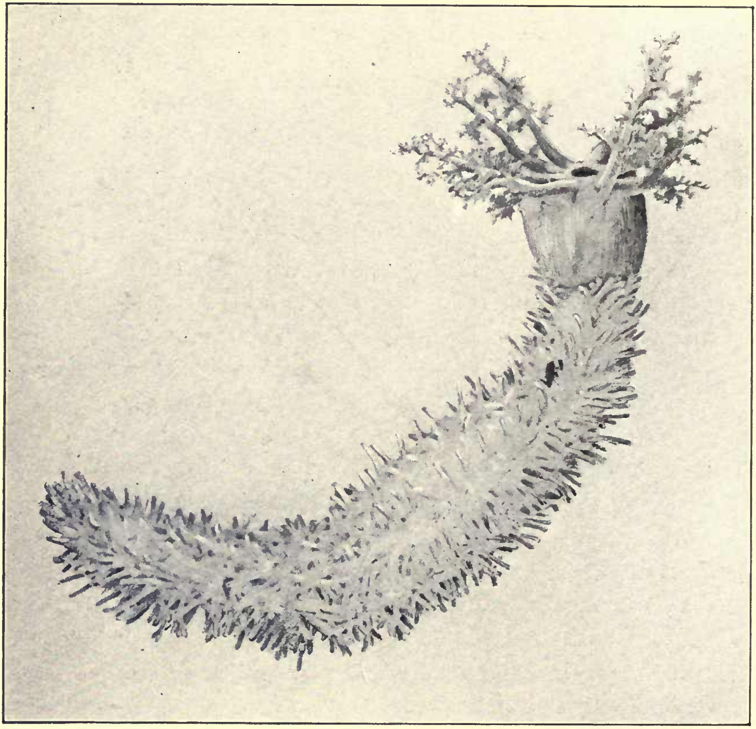


FIG. 125. Photograph of Living Sea-Cucumber. Natural size

animal was using its tentacles as well as its tube-feet to crawl along the bottom of a dish of sea-water. When the animal is at rest, the tentacles are probably used to capture small animals, and to pass them to the mouth.

Relatives of Cucumaria have been known by observers to disgorge the entire set of internal organs through the mouth-opening. In captivity they appear to do this when placed in unfavorable situations. It is not so remarkable that they should lose their internal organs, as it is that they should regenerate them all again as perfect as ever. If sea-cucumbers throw out their internal organs in nature, it would appear to be a very expensive process. Since they do perform this action, in nature as well as in captivity, there must be some reason for it. The only reason that suggests itself is based on the fact that fish prey upon sea-cucumbers. The sea-cucumber is a slow-moving animal, and once seen by a roving fish the chances of escape under ordinary circumstances would be few indeed. If the prospective victim when disturbed were to eject its internal organs into the water, the fish, true to the instinct of its kind, would gobble up the swiftly moving object, and probably go away satisfied.

Sea-cucumbers are prepared and used as food by the Chinese, and it is reported that the Siwash Indians of the northwest of the United States eat them, and sea-urchins also.

Definition of Echinoderma

Each of the five animals described in this chapter represents one of the five classes that make up the phylum *Echinoder'ma* (Gr. *echinos*, hedgehog; *derma*, skin). The five classes represented are *Asteroi'dea*, by Asterias; *Ophiuroi'dea*, by Astrophyton; *Crinoi'dea*, by Pentacrinus; *Echinoi'dea*, by Strongylocentrotus; and *Holothuroi'dea*, by Cucumaria.

The most important characteristics of the phylum are the radial symmetry of the body (the importance of this character is denied by some zoölogists); the occurrence of repeated divisions or organs of the body to the number of five, or in multiples of five; and the existence of a water-vascular system. No other phylum has parts occurring in fives, and none other has a water-vascular system.

CHAPTER XIX

THE SEA-ANEMONE AND SOME ALLIES: CŒLENTERA

To-day the many-hued anemone
Waving, expands within the rock-pools green,
And swift, transparent creatures of the sea
Dart throu' the feathery sea-fronds scarcely seen.

Sir Lewis Morris.

The Sea-Anemone. The best-known sea-anemone of the North Atlantic coast is *Metrid'ium margina'tum* (Figs. 126, 128, and 129). Although this species is usually found in tide-pools, it also lives attached to the piles of wharves in harbors where the impurities of the water are not too great. The picture of the tide-pool shows sea-anemones in various attitudes. Metridium has the power of moving, by creeping along on its base, but it seldom changes its place of attachment, even in the coldest weather.

The form of Metridium is nearly cylindrical. The base, which is the aboral surface of the animal, widens irregularly to fit the surface of attachment, thus enabling the body to maintain its hold by expelling the water from beneath the disk. The oral end of the column-shaped body expands into a crown of many small, slender tentacles. At the middle of the oral surface is the mouth. The skin of the body is soft, but rather tough. An animal with the general plan of structure of the sea-anemone is called a *polyp*.

The food of the sea-anemone consists in general of many kinds of microscopic pelagic organisms. The capture of prey is accomplished by a method peculiar to the phylum to which Metridium belongs. All over the tentacles are numberless microscopic cells containing *nettling-capsules* (compare

Fig. 126. Tide-Pool Study of Sea-Anemones, East Point, Nahant, Mass.

Fig. 127, *Hy'dra,* see p. 263). When any small animal strikes against the minute bristle (Fig. 127, *A*, 3) that arises from the external surface of one of these cells, the capsule breaks, and a slender, hollow thread or filament (Fig. 127, *B*, 4) shoots out, reversing itself from the base, like the pharynx of the sandworm, and pierces the skin of the creature. In the capsule there is some fluid which is discharged through the filament and poured into the wound. The effect of the fluid is to benumb the victim.

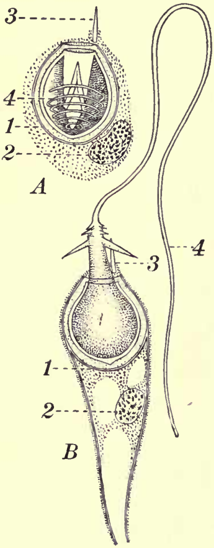


Fig. 127. Nettle-Cells of Hydra. Much enlarged. (After Schneider)

A, nettle-cell, with undischarged nettling capsule; *B*, nettle-cell, with discharged nettling capsule: 1, nettling capsule; 2, nucleus of nettle-cell; 3, bristle of nettle-cell; 4, hollow filament of nettling capsule

A sea-anemone resting in the attitude of the one shown in Fig. 128 could not swallow anything, even after the victim had been overcome. The reason is that the minute cilia which cover the tentacles wave outward at all times. As long as particles of waste and other undesirable substances fall within range of the cilia, they are swept out of the way; but whenever small animals come within range of the cilia, and are paralyzed by the nettling filaments, the tentacles bend over with their tips pointing toward the mouth. The normal action of the cilia now sweeps the helpless creatures toward the sea-anemone's mouth. All over the thick, grooved lip there are more cilia. The cilia at the opposite ends of the mouth lie in a deep, wide groove called the *siphonoglyphe* (Fig. 129, 3). Here the cilia always wave inward. At the sides of the mouth the cilia wave outward except when food is dropped on them by the cilia of the tentacles; then they reverse their action, and all the mouth-cilia unite in sweeping the food down the gullet. These observations were made by Professor G. H. Parker, of Harvard University, in 1896.

The mouth opens to receive the food, which is sometimes quite large, and the *gullet* (Fig. 129, 4) passes it down by ciliary action aided by muscular activity in the gullet-wall.

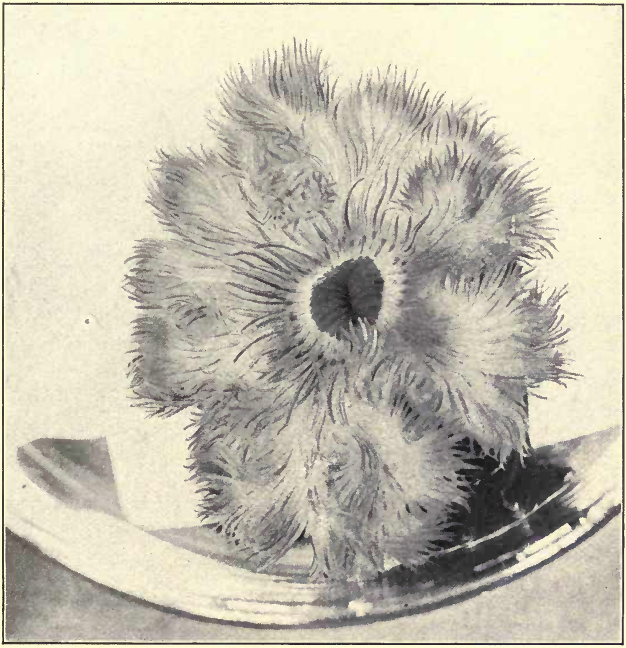


Fig. 128. Photograph of Living Sea-Anemone. Natural size

At the inner end (Fig. 129, 5) of the gullet, food passes into a large space which extends radially between *mesenteries* (partitions) (Fig. 129, 12, 13) to the body-wall. Thus there is no distinct alimentary canal separate from a body-cavity. This fact shows the sea-anemone to be a less specialized animal, and hence a lower form, than any we have yet studied. Those animals that do not have a body-cavity and an alimentary canal have but one cavity to take their place; this cavity is

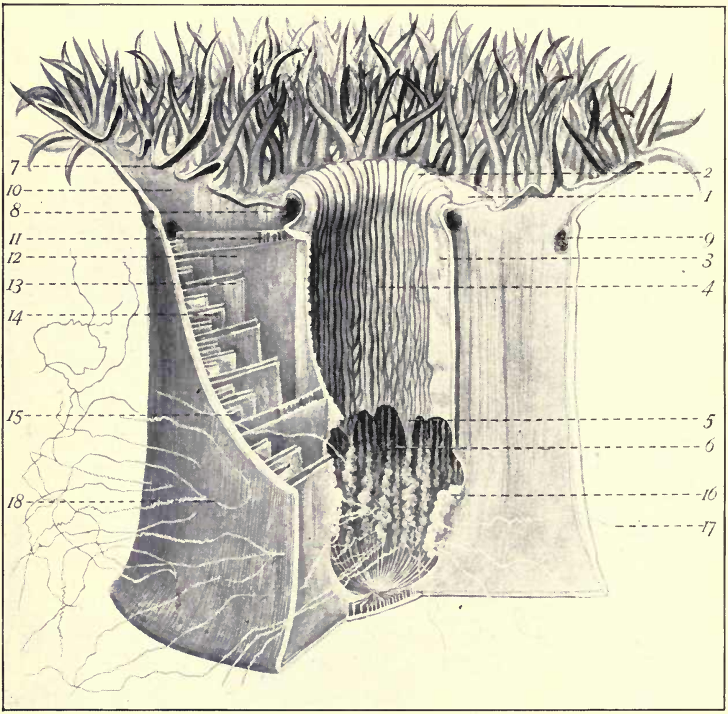


FIG. 129. Dissection of the Sea-Anemone (*Metridium marginatum*). Natural size

1, intermediate zone; 2, lip; 3, siphonoglyphe; 4, gullet; 5, inner end of gullet; 6, edge of mesentery; 7, cavity of a tentacle; 8, inner ostium; 9, outer ostium; 10, primary mesentery; 11, muscle-plate on primary mesentery; 12, abnormal tertiary mesentery; 13, secondary mesentery; 14, tertiary mesentery; 15, quaternary mesentery; 16, reproductive gland; 17, mesenterial filament; 18, opening for mesenterial filament.

called the gastrovascular cavity, because in the same space food is digested and carried about. The fact that food and oxygen can pass into any portion of the body, even into hollow tentacles (Fig. 129, 7), accounts for the absence of a circulatory system, which usually serves the purpose of transporting oxygen, digested food, and also waste products from part to part in the animal body. Likewise we find no gills or nephridia, for probably all the waste products of metabolism are sent from the cells into the gastrovascular cavity and ultimately to the outside. The absence of all these special organs is further indication of a low and simple type of organism.

There are usually six pairs of principal mesenteries in Metridium marginatum. They are thin, radial partitions extending from the gullet outward and downward to the body-wall. These six pairs are called the *primary* mesenteries (Fig. 129, 10, 11). In the arcs between the sets of primary mesenteries there are *secondary* mesenteries, also in pairs (Fig. 129, 13), arising from the body-wall and extending part way toward the gullet. The *tertiary* mesenteries (Fig. 129, 14) and the *quaternary* mesenteries (Fig. 129, 15) extend shorter distances into the gastrovascular cavity, but all unite with the body-wall of the oral and the aboral ends, and in the latter place meet at the center. Occasionally a mesentery grows beyond the usual width and becomes attached to the gullet, as in Fig. 129, 12. Every mesentery has a longitudinal *muscle-band* (Fig. 129, 11) on one side near its free or inner edge. In all but two pairs of mesenteries the muscle-bands face each other. The four primary mesenteries which are directed toward the siphonoglyphes have their muscle-bands on the outside. At the oral end there are two circles of openings called *ostia* (Fig. 129, 8, 9). They perforate all the primary mesenteries and bring the radial chambers into communication at that end.

At the free edge of the widest mesenteries below the end of the gullet there are to be found coiled masses which are composed chiefly of mesenterial filaments (Fig. 129, 17, 18).

These filaments are thickly set with microscopic nettle-cells, like those shown in Fig. 127. When the animal is disturbed greatly, the mesenterial filaments stream out through the mouth and through small invisible openings in the body-wall. It is likely that the most frequent use of the mesenterial filaments is in defense.

The egg-cells and the sperm-cells of Metridium are found in separate individuals, and adjacent to the mesenterial filaments (Fig. 129, 16). The development of Metridium has not been studied, but in kindred species embryologists have found that the eggs are fertilized while they are still in the mesenteries. At a certain stage of development the embryo is freed. It passes out through the mouth of the female, swims awhile by cilia, and finally settles and continues life after the manner of the adult. Reproduction takes place probably most frequently by *budding* (the formation of small individuals on the edge of the aboral surface), and, rarely, by longitudinal division into halves.

Wherever the sea-anemone lives, in tide-pools, on piles of wharves, on rubble beaches, or in the deeper waters of bays, it has to contend with whatever unfavorable conditions characterize the place. The periodic fall of the tide leaves some individuals exposed to the drying effect of the air. They meet the conditions by contracting the organs of the oral end, and exposing as little surface as possible to the air (Fig. 126). On account of their tough skin, their nettle-cells, and their ability to hold to a fixed support, it is not likely that adult sea-anemones are ever attacked by fishes or other ravenous animals. We cannot tell how many of the pelagic young sea-anemones are lost by being swept upon the beach, or how many are carried far out into the ocean, or swallowed by larger animals. Undoubtedly the number is very great.

The protection insured to the adult sea-anemone by its tough skin and its nettle-cells is considerable, and we find no relation between the color of the animal and the color of the objects in the environment. In the same situation one may find all variations of uniform or mingled shades, from light yellow to dark brown, — a fact which of itself would indicate that the animal does not depend on color-resemblance for protection.

The Coral Polyp. The only coral polyp of the North Atlantic coast is *Astran'gia da'næ* (Fig. 130). It occurs in colonies of many individuals and incrusts rocks or pebbles

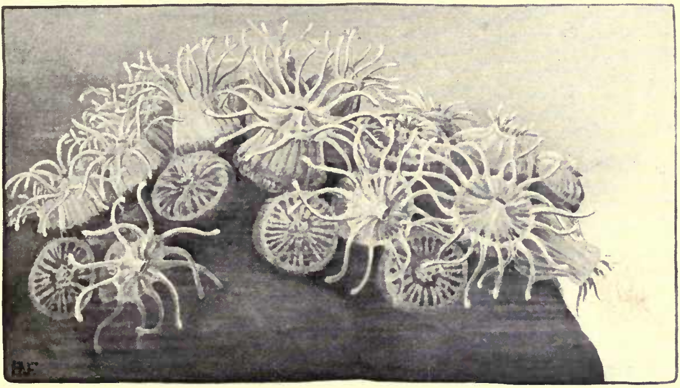


Fig. 130. Colony of Coral Polyps. Enlarged

in shallow water, near the shore line from Massachusetts to North Carolina.

A polyp of Astrangia is about one eighth of an inch in diameter and of variable length. It bears a very obvious resemblance to a sea-anemone. The columnar form, the flattened aboral surface resting on a support, and the oral end with its crown of tentacles, prove the relationship. Besides, examination of the interior reveals the presence of mesenteries arranged very much as in Metridium. One important structure of Astrangia, however, is never found in the sea-anemone, and that is the carbonate of lime "skeleton." This structure at the base of the polyp is more definitely referred to under the name *corallite*, for it is not a true skeleton. Several corallites are shown in the lower portion of the figure. The hard, radial plates repeat the number of pairs of mesenteries of the polyp, since each plate is formed between the members of pairs of mesenteries.

The aboral surface of the polyp is molded over the corallite so that the soft tissue of the animal extends down between the radial plates, and also over the circumference. Although the polyp may be said to fit into the corallite, it is the real cause of the existence of the corallite.

The substance of the corallite is formed by the crystallization of carbonate of lime in the epidermal cells of the polyp. Crystallization takes place in the outermost cells, and as the substance in them hardens newer cells are formed just within, and in these the process of crystallization continues. Thus it is that as the coral polyp grows, it actually pushes itself farther and farther away from the surface to which it became attached at the beginning of its fixed life. Astrangia has a characteristic method of forming a colony. The height of a corallite does not exceed a half-inch. The colony increases by budding from the older polyps at their bases. The result is a low mass of corallites that seldom exceeds an area of four inches square.

Definition of Actinozoa (Gr. *aktis* (*aktin*), ray; *zoön*, animal). The members of the class *Actinozo'a* are alike in having a soft, generally cylindrical body. The plan of structure is bilaterally symmetrical, as indicated in the arrangement of mesenteries in the gastrovascular cavity, it being possible to pass a line lengthwise through the mouth to opposite siphonoglyphes, and separate one half the mesenteries from the other half. Superficially, however, as indicated by the arrangement of the tentacles, there is radial symmetry. Into the single, partially divided gastrovascular cavity the mouth opens, and through it food enters and unused particles are discharged. Nettling-capsules, which are the organs of offense and defense, are at the surface of the tentacles and on the mesenterial filaments.

Coral Islands. Ever since Charles Darwin from 1831 to 1836 made his famous journey around the world in H.M.S. *Beagle*, scientific explorers have engaged from time to time in the study of the life and structure of coral reefs and islands. We know from their researches that coral reefs are formed of great masses of carbonate of lime, largely as the result of the secretion of that substance by polyps.

Just as with other organisms, reef-forming polyps flourish wherever they become adapted to external conditions. The food they need is probably abundant anywhere in the seas, but they cannot endure the temperature common to regions outside the torrid zone. They can live in situations where the tide recedes from them for two or three hours, or in depths as great as fifty fathoms (300 feet), but the most general limit of depth for the greatest number of species is about twenty fathoms. A condition which checks their distribution near large bodies of land is the presence of silt, as in the fresh water that flows from the mouths of rivers. Fresh water itself when free from impurities is not especially detrimental to the growth of coral polyps. The most famous coral formations are found in the region of the Bahama Islands, in the Great Barrier Reef of Australia, in the Fiji Islands of the South Pacific Ocean, and in the Maldive Islands of the Indian Ocean.

When conditions permit, young coral polyps attach themselves to the sea-bottom near a body of land, and by the process of secreting carbonate of lime, as described for Astrangia, extend upward toward the surface in the form of a long, narrow ridge skirting the land. When the ridge is so near the land that it leaves no channel, it is called a *fringing reef.* If by subsequent changes, or as originally formed, a navigable channel lies between the ridge and the land, it is called a *barrier reef.* If the formation surrounds a body of water, which it nearly or completely cuts off from the sea, it is called an *atoll.* The most remarkable examples of atolls are the Maldive Islands.

Two important theories have been advanced to account for the historical connection which in many cases is thought to exist between fringing reefs, barrier reefs, and atolls. Darwin believed that an atoll begins as a fringing reef surrounding an oceanic island, which may be of volcanic or other origin, and that as the island sinks from internal causes, the coral polyps build up carbonate of lime as long as they are within their range of favorable depth. The reef that at first was a fringing reef becomes a barrier reef, on account of the increase in distance between it and the decreasing area of sinking land. At last the top of the island disappears beneath the water, and the atoll remains. Professor J. D. Dana, and others, have published evidence in support of Darwin's *subsidence theory*, but the *erosion theory* suggested by Dr. John Murray, leader of the exploring expedition of H.M.S. *Challenger* (1850), has probably more adherents at the present day. The erosion theory has been modified and extended, chiefly by Dr. Alexander Agassiz. According to this theory coral polyps may form a fringing reef about an oceanic island. The reef continues to grow, while the soil or rock of the island is carried away by rains and by rivers. The solution of the soil and rock is caused by the temporary chemical union of these substances with carbon dioxide derived from dead animals and plants. The idea is that in the course of a few centuries an entire island could be worn away, and the atoll left with its lagoon of water partially connected with the sea.

Dr. Murray suggested also the probability of atolls being formed without the preliminary stages of fringing and barrier reefs. If coral polyps were to attach to a submerged plateau not too deep for them to live on, the small colony would grow upward and extend itself radially, something like the flaring sides of a shallow wash-basin. As the mass grows larger the polyps at the center would be killed by the detritus collecting from the broken pieces of coral rock at the wave-beaten margin, and the rock already formed at the center would be worn and scooped out by erosion with coral sand.

Coral atolls are imperishable bulwarks against the sea, and in some cases have formed the beginning of strips of land sufficiently wide for wild races of men to live upon.

The Fresh-Water Polyp. There are but two species of fresh-water polyps that are at all common, and these are so small that the casual observer would seldom be aware of their existence, even though they were abundant in his aquarium. The two species are *Hy'dra vir'idis* (Fig. 131), the green hydra, and *Hydra fus'ca*, the brown hydra.

Hydra viridis lives among green fresh-water plants in places where there is abundant sunlight. At rest it holds to a plant with its aboral surface, the remainder of the body floating outward or downward very much like the sea-anemone. The body, which is cylindrical in form, is about 3 mm. ($\frac{1}{8}$ inch) long and .4 mm. ($\frac{1}{60}$ inch) in diameter. A little practice will enable a person to distinguish one in an aquarium, for specimens frequently leave the green plants and crawl up the side of the glass nearest the light. They can move either by a slow, creeping movement on the aboral surface, or by the process of "looping," like an inchworm. Hydras exist for a long time in an aquarium, provided there is an abundance of their food-animals, which are usually small Crustacea. The most common of these is a fresh-water species of Cyclops (resembling Fig. 75), which they benumb with their nettling-threads, and carry to the mouth with their tentacles.

The number of tentacles a specimen of Hydra viridis may have depends upon its size, and also upon its age. The small individuals are generally the youngest; these have four tentacles. The larger, older ones gain in the number of tentacles, up to the extreme number of eleven; but there is a greater per cent of individuals with six tentacles than with any other number.

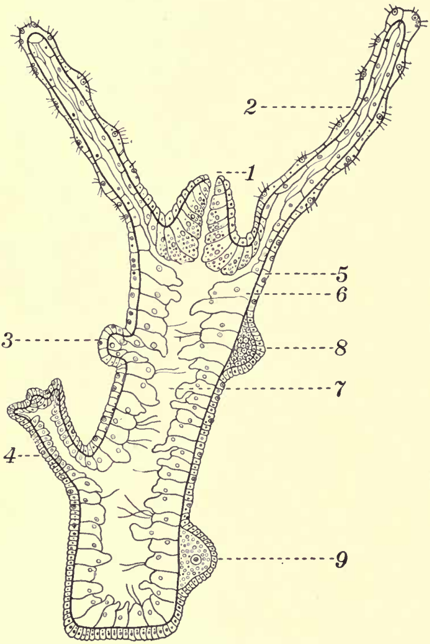


FIG. 131. Fresh-Water Polyp. Longitudinal section. Much enlarged

1, mouth; 2, tentacle; 3, forming bud; 4, older bud; 5, ectodermal cells; 6, endodermal cells; 7, gastrovascular cavity; 8, spermatozoa forming; 9, egg forming

(From Parker's *Elementary Biology*)

Internally, Hydra is the simplest animal we have studied. The mouth (Fig. 131, 1) opens into a cylindrical cavity (Fig. 131, 7) with no indication of gullet, or radial partitions. The cavity extends by slender tubes out into each tentacle, and in all parts only two layers of cells separate it from the water outside. The inner one of these two layers is the endoderm (Fig. 131, 6), and the outer one, the ectoderm (Fig. 131, 5). Cells of the endoderm secrete fluid for digesting food, and even take up small particles of food, digesting them inside the cell-substance. The ectodermal cells are modified into nettle-cells, nerve-cells, muscle-cells, and general surface-cells.

Reproduction may take place by the sexual method, or by budding. Eggs (Fig. 131, 9) are developed in the ectoderm near the aboral end. In the same individual spermatozoa (Fig. 131, 8) are formed in the ectoderm nearer the oral end, and these on escaping fertilize the eggs, which remain in the ectoderm for some time as embryos. Then the embryos separate from the parent, and after swimming about for a variable period develop into organisms like the parent. Nonsexual reproduction is the more frequent method, however. Buds involving both ectoderm and endoderm form on the side of the body (Fig. 131, 3, 4); four tentacles appear, the mouth forms, and the base of the bud constricts, setting the young Hydra free to begin its own career.

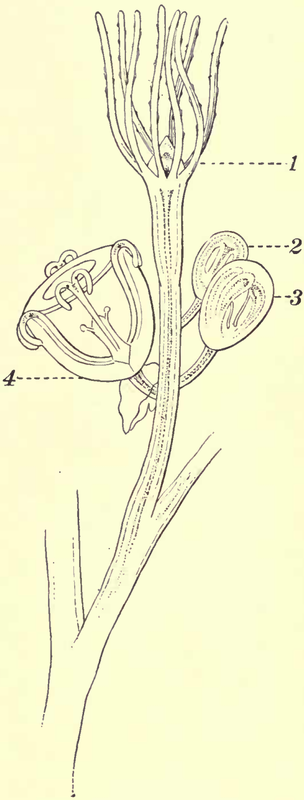


Fig. 132. Hydroid. Much enlarged. (After Allman)

1, tentacles; 2, 3, 4, stages in the formation of medusa

Hydroids and Medusæ. There is a large group of animals closely allied to Hydra, that live in the sea. A portion of one of them, *Bougainvil'lia frutico'sa*, is shown in Fig. 132. It looks very much like a plant, owing to its habit of branching. The colony may contain many polyps, each of which is connected indirectly with every other by means of the continuous body-wall. At the base of the colony, root-like branches from a stem-like structure cling to floating timbers or buoys. Although the colony reaches the height of two inches, the individual polyps are microscopic in size. Each polyp has about fourteen tentacles amply provided with nettling capsules, which aid in capturing small pelagic animals. The mouth is at the center of the circles of tentacles (Fig. 132, 1); it opens directly into the gastrovascular cavity. As the branches are terminated by feeding polyps, the cells of the branches are probably supplied with food by the polyps nearest at hand.

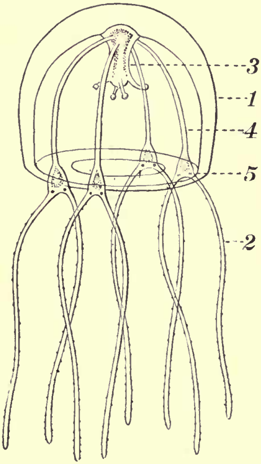


FIG. 133. Medusa. Much enlarged. (After Allman)

1, bell; 2, tentacle; 3, manubrium; 4, radial tubes; 5, sense-organs

Reproduction in Bougainvillia may be a mere increase in the number of polyps by a process of budding similar to that described for Hydra. Occasionally, however, a bud develops into a structure totally different from an ordinary polyp, and after a series of stages indicated in Fig. 132, 2, 3, 4, finally becomes separated from the colony and floats away as a free-swimming individual (Fig. 133). This is called the *medusa* stage of the animal. The medusa has something like the shape of an umbrella. The mouth is located at the end of the pendent *manubrium* (Fig. 133, 3). The gastrovascular cavity sends out four slender tubes (Fig. 133, 4) radially to the perimeter, where a circular canal joins them. Tentacles (Fig. 133, 2) stream downward from the margin, and at their bases are minute sense-organs (Fig. 133, 5).

There are male and female medusæ. The ovaries and the spermaries of Bougainvillia are located in the manubrium. When the eggs and spermatozoa are ripe, they pass out through the mouth, and fertilization takes place in the water outside. The embryo swims about for awhile and then settles to some fixed or floating object, attaches itself, and soon another colony of the hydroid (hydra-like) stage is developed by budding. The life-history of Bougainvillia illustrates *alternation of generations.* The fixed, colonial, non-sexual, hydroid stage alternates with the free-swimming, single, sexual, medusa stage, and together they complete the life-cycle.

Definition of Hydrozoa (Gr. *Hydra*, the fabulous monster; *zoa*, animals). The class *Hydrozo'a* includes the genus Hydra and many thousands of species of hydroids. The life-history described for Bougainvillia by no means applies to all species of hydroids, but it is as characteristic as any. Hydrozoa are small animals occuring singly and in colonies. There is but one cavity in the body, and that is continuous with the mouth-opening. There are but two layers of cells, the ectoderm and the endoderm. In some members of the class the two layers are separated by a jelly-like mass secreted by the cells. The body is radially symmetrical. Tentacles with nettling-capsules in their ectodermal cells are the organs of offense and defense.

The Jellyfish. Although the name "jellyfish" is sometimes applied to the medusæ of the class Hydrozoa, it is more commonly given to the larger, saucer-shaped or bell-shaped animals that swim at or near the surface in harbors and bays of all lands. The species most frequently found from Massachusetts southward is *Aure'lia flavid'ula* (Fig. 134). This jellyfish reaches the diameter of fifteen inches.

In various details of structure Aurelia resembles the medusa of certain hydroids, and also the sea-anemones, the coral polyp, and the fresh-water polyp. The mouth opens at the center of the under surface into a large cavity which branches freely into many tubes running to the circumference, where they join the circular canal. Between the ectoderm covering the body, and the endoderm lining the gastrovascular cavity, is a great mass of jelly secreted by the cells of the two layers. Hanging from about the mouth are four broad ribbon-like appendages called "lips." These and the delicate fringe of tentacles at the rim of the bell are covered with nettle-cells. Nettle-cells are found also on the mesenterial filaments which lie in the radial canals.

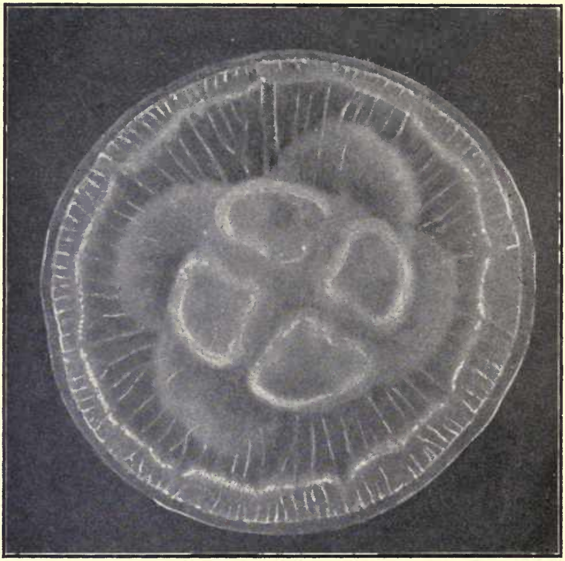


FIG. 134. Photograph of Jellyfish. Reduced

A very noticeable detail of structure that one observes in watching these animals in the water, especially in the late summer, is the set of four partial rings about the center, yellowish in color in the males and reddish in the females. These rings are the sexual glands. They are sacs which contain the eggs or spermatozoa until these cells are ready to be discharged through the radial canals and the mouth. On the rim of the bell, at eight equidistant points, are small, rounded sense-organs, which have the function of controlling, through the nervous and muscular systems, the direction of movement of the jellyfish. The most important muscle is a circular band near the rim. The nerve-cells are grouped near the sense-organs, and connect the latter with the muscle-band. When the circular muscle contracts, the bell becomes more convex, and the resulting action of the water in the hollow of the bell against the water outside, sends the animal along in a slow, periodic, pulsating movement.

The development of Aurelia is very different from that of the hydroids. The simple, free-swimming larva of Aurelia sinks to the bottom, attaches itself to some fixed object, and takes on a form resembling Hydra. The formation of circular grooves below the tentacles develops a series of saucer-like divisions, one within another. These separate and, swimming away with the convex, aboral surface uppermost, grow into the adult form. The fixed stage is comparable with the hydroid generation of Hydrozoa.

Aurelia is but slightly more dense than the sea-water itself. According to one authority there is less than one eighth of one per cent of proteid material present. Thus over ninety-nine per cent is water. The small amount of proteid material in the body of Aurelia makes it very unlikely that many animals depend on them for food. After a storm in summer great numbers of Aureliæ may be found on the shore. In a few hours only scattered films are left on the sand to show where the animals lay. The destruction of many Aureliæ is to be expected because of their general helplessness, but annihilation of the species is prevented by the enormous number of young produced.

The great fecundity of Aurelia and its giant relative *Cya'nea* which sometimes grows to a diameter of eight feet, might threaten to fill the ocean with their bodies, were it not for the fact that neither lives over the winter. The young start their development in the autumn and complete it in the spring. It is a self-evident fact, in this instance at least, that death is a benefit, not only to all other forms of sea life, but even to the race of Aurelia itself. The adults swallow everything that can be taken into the mouth, but probably their most abundant food is small pelagic Crustacea similar to Cyclops (Fig. 75).

The class of which Aurelia flavidula is a representative is called *Scyphozo'a* (Gr. *skyphos*, cup ; *zoa*, animals).

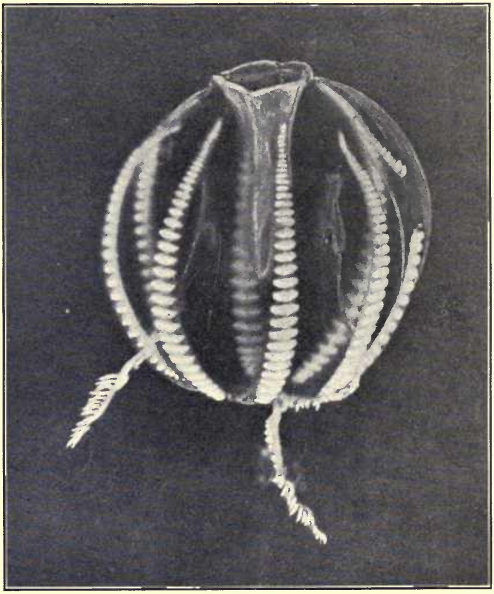


FIG. 135. Photograph of Comb-Jelly. Enlarged

The Comb-Jelly. The species of "comb-jelly," or "sea-walnut," shown in Fig. 135 (*Pleurobrach'ia rhododac'tyla*), is found in the colder seasons floating at the surface along the North Atlantic coast. It is about as large as a hazelnut, but greater in diameter vertically than tranversely.

The body of the comb-jelly is soft like that of the jellyfish, but the plan of structure and the organs are somewhat different. There are eight meridional bands of comb-like structures, which serve the animal as locomotor organs. During locomotion these combs move vigorously, and in such a way that beautiful iridescent effects are produced by them. Near the lower end, as shown in the figure, there are two fringed tentacles with such wonderful powers of extension that from a mass no larger than a pin-head they can extend over a foot. The tentacles have minute adhesive cells which are thought to be modifications of nettling-capsules, or structures which take the place of them. By means of the adhesive cells the tentacles hold small animals and pass them to the mouth. As the animal swims the tentacles are below and the mouth above. A funnel-shaped space at the upper end carries the food into the mouth. The gastrovascular cavity extends into two lateral pouches from which two branches arise, making four; each of the four branch-tubes gives rise to two, making eight altogether. Each of the eight branch-tubes joins a meridional tube which lies just beneath the bands of combs. Food carried in at the mouth can thus pass to any portion of the body. At the end opposite the mouth there is a small sense-organ, which is the center of the animal's nervous system. Every comb-jelly contains both egg-cells and sperm-cells. The eggs are fertilized outside the body, and the young larvæ swim free and gradually develop into the adult form. The comb-jelly produces a phosphorescent light when disturbed.

The class of which Pleurobrachia rhododactyla is a representative is called *Ctenoph'ora* (Gr. *kteis* (*kten*), comb; *phero*, bear).

Definition of Cœlentera (Gr. *koilos*, hollow ; *enteros*, intestine). Arranged in the order of their increasing degree of specialization, the four classes that make up the phylum

Cœlen'tera are Hydrozoa, Scyphozoa, Actinozoa, and Ctenophora. The classes constitute a fairly distinct phylum by including animals with radially symmetrical bodies (at least in external appearance) in which there is but one cavity. This cavity, joining the mouth-opening, is the digestive cavity, and is not separated from a body-cavity, as in higher animals (whence the derivation of the name of the phylum). The body develops from an embryo that has two germ-layers, — the ectoderm and the endoderm. In this particular it is different from every phylum of animals heretofore described. The characteristic organs of offense and defense are the nettling-capsules. By some authorities the Ctenophora are separated into a phylum by themselves, partly because they do not possess nettling-capsules.

CHAPTER XX

THE FRESH-WATER SPONGE AND SOME ALLIES: PORIFERA

> The unending shapes of plants, the rainbow's varied hues,
> All these, the lowly sponge on ocean's bed renews.

The Fresh-Water Sponge. The sponge illustrated in Fig. 136 (*Heteromeye'nia ry'deri*) is found quite generally in ponds and quiet brooks, at least as far west as the Mississippi River. It grows on the under side of overhanging submerged rocks, and on dead sticks and leaves. The largest specimens are not usually more than one inch across. Each mass of sponge clings flat against the supporting substance, and seldom is more than one eighth of an inch thick. The sponge yields slightly on being pressed with the finger. The surface looks rough, but to the touch it is smooth. The color is grayish; occasionally specimens are found with a part or all of the mass green. This is due to the presence of a green alga growing in the sponge.

The first thing that attracts one's attention in the drawings of the fresh-water sponge is the many small, circular holes, *oscula* (sing. *osculum*, a little mouth), scattered over the surface. They are openings through which the waste, the unused food, and water are expelled from the sponge. Everywhere between the oscula are numerous very small holes, *dermal pores* (compare Fig. 137, *b*), which open into quite large subdermal chambers. Leading from the subdermal chambers are short canals called *incurrent canals*. These lead to cavities lying deeper in the sponge, the *ampullæ* (Fig. 137, *c*), which are lined with cells that bear *flagella* (lashes). These cells are called *collar-cells*, on account of their having a collar-like membrane around the base of the flagellum. The flagella wave inward and cause a current of water to flow into the sponge through the minute dermal pores and along the incurrent canals, past the collar-cells into the *excurrent canals*. Water passes

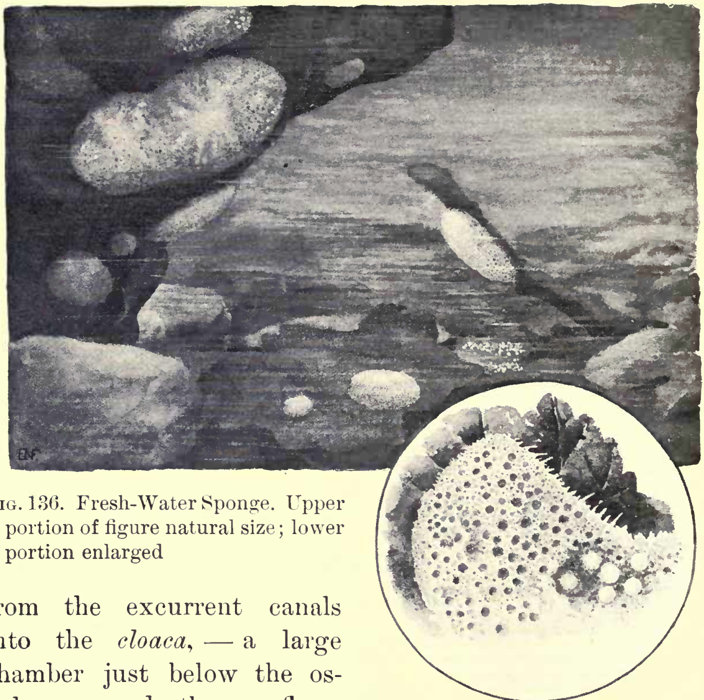


FIG. 136. Fresh-Water Sponge. Upper portion of figure natural size; lower portion enlarged

from the excurrent canals into the *cloaca*, — a large chamber just below the osculum, — and thence flows out of the sponge through the osculum (Fig. 137, *d*).

Food consisting of microscopic plants and animals is drawn in at the dermal pores and carried along by the current. Very small particles are taken into certain cells along the canals and digested there, as in the endodermal cells of Hydra. Larger particles are surrounded by *wandering cells* and digested little by little. Digested food passes by osmosis to all the cells of the sponge.

The fresh-water sponge has no special digestive organs, no circulatory system, respiratory system, muscular system, nervous system, nor sense-organs. Food and oxygen are carried in together, and oxidation takes place freely because oxygen can go anywhere within the sponge. The oscula sometimes contract when the sponge is disturbed, but this action takes place because of the power of contracting which is possessed by certain cells that are not true muscle-cells. There are, however, two important systems of organs possessed by the fresh-water sponge: a set of structures which constitute the skeleton, and special cells for reproduction. The substance which serves as a skeleton supporting the soft, protoplasmic cells, is made up of microscopic *spicules* (compare Fig. 139) of various forms, and of very hard material called silica. These spicules, interlacing and crossing one another, give a very firm texture to organisms that would otherwise be formless and slimy.

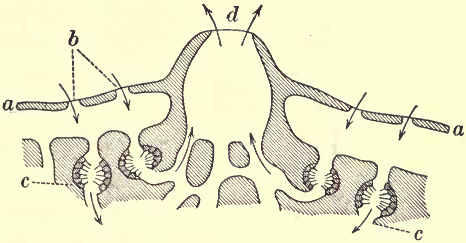


FIG. 137. Section of Fresh-Water Sponge (*Spongilla*). Much enlarged (After Huxley)

a, surface; *b*, dermal pores; *c*, ampullæ, lined with collar-cells; *d*, osculum

Certain cells along the canals develop eggs and spermatozoa. Each sponge-mass is capable of producing both kinds of cells, but not at the same time. While some masses are producing eggs, others in the same pond or brook are producing spermatozoa. The eggs are retained in position on the canals, while from other specimens the spermatozoa escape and swim out into the water, to be drawn later, quite by accident, into the incurrent canals of sponges with eggs. The eggs are fertilized and immediately begin the process of development.

When the embryo has reached the blastula stage it is set free, and swims out through the osculum. The larva, in *Spongil'la*, another fresh-water sponge, and probably in Heteromeyenia as well, is shaped like a hen's egg, but is very small and is covered with collar-cells bearing flagella, which are the organs of locomotion for the few hours of free life which the larva has. When it comes to rest it attaches itself by the broad end, and grows into the form of the adult.

Fresh-water sponges reproduce also by means of special organs called *gemmules*, which are about one-fiftieth of an inch in diameter (Figs. 136 and 138). These structures are produced in the sponge-mass toward the end of August. Their use is to carry the species over the unfavorable season after the destruction of the parent sponge, which usually takes place in the fall. They are admirably protected by the three layers of material which form the horny covering. The double-headed spicules give stiffness to the whole gemmule. Inside is a mass of cells containing food-material; these cells remain in a state of inactivity until the return of favorable conditions. Then the contents of the gemmule forces itself through the thinly covered pore, and soon forms a minute sponge with incurrent canals and a single osculum, which, as Professor Potts says, "puffs out material after the manner of a miniature volcano."

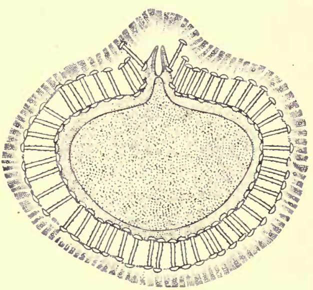


Fig. 138. Gemmule of Fresh-Water Sponge. Much enlarged. (After Evans)

By far the greater number of species of marine sponges, and all fresh-water sponges, are composite in character. In hydroids it is easy to distinguish one individual of a colony from another, but in fresh-water sponges the only clew one can get to the number of individuals is that furnished by the number of oscula. The evidence obtained through studying the embryology of sponges indicates that each osculum marks the position of an individual, and that the adult form results from the fusion of numerous individuals originally distinct. Internally, however, there is no separation between individuals, their chambers being continuous.

Sycon. Some sponges that live in the sea are simple; that is, they consist of a single individual. A sponge of this kind is *Sy'con* (Fig. 139). The free end has a single osculum. All over the body elsewhere are minute dermal pores leading into incurrent canals, alternating in the substance of the body-wall with radial canals. Food and water entering the incurrent canals by dermal pores are carried into the adjacent radial canals by short canals. From the radial canals the water passes into the large cloaca. Waste and extra water are discharged through the osculum. The spicules are composed of carbonate of lime.

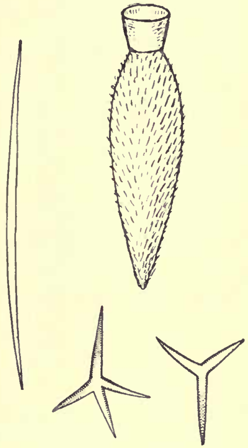


Fig. 139. Sycon and Spicules. Sponge enlarged; spicules much enlarged. (After Grentzenberg)

The Bath-Sponge. The best known of all species of sponges is, of course, the bath-sponge (*Euspon'gia officina'lis*). It is a composite sponge of great complexity, but usually the oscula, looking like chimneys, stand out so clearly that one may determine the number of individuals present in a mass. Varieties of this sponge are found in the deep waters about the Bahama Islands and in the Mediterranean Sea, especially on the coast of the Turkish dominions.

The bath-sponge grows attached to rocks in water of a few fathoms' depth. Divers cut the masses at the base and later throw them upon the beach, where the soft portion rots and dries. Then the remainder, which is the skeleton, is cleaned and made ready for the market. These sponges are valuable for the uses of man on account of the softness of the whole skeleton and the tenacity of its substance. The skeleton is composed of tough, anastomosing fibers of horny material instead of spicules of silica, as in Heteromeyenia, or of carbonate of lime, as in Sycon.

Relation to Environment. Perhaps no group of animals has so wide a distribution in water as sponges. In fresh water, and in the sea from the very margin of low tide to the greatest depth of ocean yet explored, and in all zones, various species of sponges are found. They live in every conceivable situation, adapting themselves in form of mass to the particular place in which they grow. Branched species, like *Microci'ona prolif'era*, in the frontispiece, vary much in form and arrangement of branch. Incrusting species on rocks, as in the frontispiece, and as shown growing about barnacles, Fig. 77, follow every turn of the supporting substance. One species of *Clio'na* grows on shells of mollusks, and through the agency of a secretion of its protoplasm consumes the substance of the shell and grows to fill the space thus made. In regions where the ocean-bottom is muddy, sponges grow stalks that keep the mass away from the mud, which if stirred up would smother the colony.

Many marine sponges being thick and massive, and of loose texture, like the sulphur sponges, are very convenient harbors of refuge for myriads of small animals, chiefly Crustacea and worms. Undoubtedly the odor of living sponges, described by one investigator as resembling garlic, drives away fishes and other ravenous animals of large size that might feed on the little guests, or even on the sponge itself.

Definition of Porifera (Lat. *porus*, pore; *ferre*, to bear). By most investigators the sponges are considered a distinct phylum *Porif'era*, including only a single class. It is evident that the Porifera are lower in organization than the Cœlentera, for the members of the phylum do not show indications of muscle-cells, of nerve-cells, or of sense-organs. Neither are there special organs of offense. Protection is afforded by the spicules and the characteristic odor. Sponges are the lowest animals which reproduce by eggs and spermatozoa. In development two germ-layers are present, ectoderm and endoderm, and a middle undifferentiated layer called the *mesoglœa*.

CHAPTER XXI

AMŒBA AND SOME ALLIES: PROTOZOA

Gradual, from these what numerous kinds descend,
Evading even the microscopic eye!
Full nature swarms with life, — one wondrous mass
Of animals, or atoms organized.

JAMES THOMSON, *Summer.*

Amœba. The amœba (*Amœ'ba pro'teus*, Fig. 140) is common in stagnant water of all lands, but it is so minute that it is impossible to be sure of its presence in a given place until examination has been made with a compound microscope.

One of the best ways to find large specimens of the amœba is to remove carefully from the bottom of a well-stocked fresh-water aquarium a few dead leaves. A medicine-dropper full of material from the surface of one of the leaves may yield several specimens. A short time after a few drops of the water have been mounted on a glass slide the Amœbæ will exhibit the characteristic structure and activities. The usual diameter of an amœba is about .5 mm. ($\frac{1}{50}$ inch).

The beginner in microscopy is very likely to overlook an amœba altogether, or to think in his anxiety that every little irregular clear spot in the field of his microscope-objective is one. The active amœba is never the same in appearance in consecutive moments. The outline, at all times irregular in locomotion, constantly becomes more or less so, by the increase or decrease in prominence of little processes called *pseudopodia* (false feet), which extend in one or several directions.

Amœba is a complete organism, although it is composed of a single cell. The substance of the cell is protoplasm, — that complicated substance without which life cannot exist. The principal organ of the cell is the *nucleus*, composed of protoplasm more dense than that which surrounds the nucleus. Frequently zoölogists distinguish the protoplasm of the nucleus, *nucleoplasm*, from that of the cell-body or *cytoplasm*. The nucleus is usually quite difficult to see unless the amœba is killed by chemicals and its protoplasm "fixed" and stained. The cytoplasm is finely granular all through, except for a thin layer on the surface, which is always clear and without granules. The granular part of the cytoplasm is called *endoplasm*, and the non-granular sheath the *ectoplasm*.

Fig. 140. Amœba. Much enlarged (From Sedgwick and Wilson's *General Biology*)

During locomotion the pseudopodia are first formed of the ectoplasm, the endoplasm following immediately and continually in the same direction that the ectoplasm takes. The method of locomotion in Amœba, as stated by Professor H. S. Jennings, of the University of Pennsylvania, is as follows. "Locomotion in Amœba is a process that may be compared with rolling, the upper and lower surfaces continually interchanging positions. This is shown by observation of the movements of particles attached to the outer surface or imbedded in the ectosarc [ectoplasm] of the animal. Such attached particles move forward on the upper surface and over the anterior edge, remain quiet on the under surface till the body of the amœba has passed, then pass upward at the posterior end, and forward on the upper surface again. Single particles may thus be observed to make many complete revolutions."

When the advancing pseudopodia come in contact with a minute unicellular organism, the object may be enveloped; if so, it gradually sinks into the cytoplasm, the amœba meantime continuing its rolling locomotion; if the object is useless for food, the amœba simply rolls over it, leaving it behind. Food is taken in with a small amount of water which forms a surrounding bubble or *vacuole*. This food-vacuole is carried about in the endoplasm and slowly disappears in the process of digestion, which goes on quite as effectively in the amœba as in any of the higher animals. The indigestible particles of the food are left behind as the amœba rolls along.

All the other phases of metabolism go on as in many-cell animals, except that in the amœba everything must be done in the one cell. The oxygen which the animal needs probably comes in through the general surface of the ectoplasm by osmosis. Oxidation and the release of energy take place, as is manifested in locomotion. The waste of the body is probably partly expelled by the *contractile vacuole*. This organ may be observed in that portion of the ectoplasm which is behind in locomotion. The products of metabolism when brought into that region form a sphere of liquid which, as it increases in size, is carried back from the region of the nucleus to the point where it contracts and bursts on the surface.

Reproduction in Amœba is accomplished by the nucleus and the protoplasm dividing into equal portions, the two new cells separating immediately and growing to the size of the original one. This kind of reproduction is considered by many zoölogists to be a phase of growth. The cell, by feeding, becomes so large that the surface through which food and oxygen pass is not great enough to supply the more rapidly increasing volume of cytoplasm. When division takes place, masses are produced which have enough surface to supply the interior with material for growth and other forms of energy.

Under certain conditions of the environment the amœba ceases moving about; it takes on the form of a ball, and incloses itself in a membrane or cyst. The encysted amœba remains in that state until the return of favorable conditions in its habitat.

Euglena. A relative of Amœba, found in the same situations, is *Eugle'na vir'idis* (Fig. 141); it also is composed of one cell. Euglena has a more fixed arrangement of parts than Amœba. There is a blunt anterior end with a short, funnel-shaped mouth to carry food into the cytoplasm. Out of the mouth extends a long lash, which by its whip-like vibrations carries the animal through the water, and at the same time sends food back to the mouth. Behind the mouth is a small red eye-spot, which lies beside a clear space. This clear space has been found to be sensitive to light. The nucleus is near the middle of the body, and can be seen easily in the living animal, although the cytoplasm immediately about it is colored quite green with chlorophyll, — a coloring matter found in the green parts of plants.

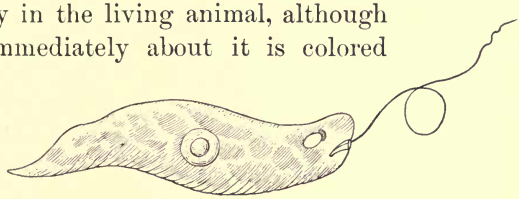


FIG. 141. Euglena. Much enlarged. (After Saville Kent)

Many biologists believe that Euglena is indeed a plant because, through the agency of its chlorophyll, it can use carbon dioxide as a raw food-material, retaining the carbon and giving off oxygen when the organism is in the light. This creature illustrates the fact that it is impossible to classify all organisms as plants or animals.

As a rule Euglena moves with the lash forward, but the animal can turn in any direction, and can even change the shape of its body considerably, but it does not form pseudopodia. Sometimes when being experimented on with substances which it does not like, Euglena ceases moving, contracts into a ball, and encysts itself, just as it does in nature when it is surrounded by unfavorable conditions.

The Malarial Parasite. Many one-cell animals are parasitic. One of the most studied in recent years is the malarial parasite of man (*Plasmo'dium mala'riæ*, Fig. 142). The life-history of this organism is long and complicated, but we can get a fair understanding of its principal phases without discussing the minutest details.

In its simplest form the animal resembles an extremely small amœba. In that stage it is found in the red corpuscles of human blood. There the parasite increases in size until it almost fills the corpuscle (Fig. 142, 4); then it divides into small bodies called *spores* (Fig. 142, $5a^{V}$). The process of spore-formation causes the chill that accompanies malaria. When the spores burst from their spore-case (Fig. 142, $5a^{VI}$) and from the blood-corpuscles, a quantity of poisonous material (represented by black dots in Fig. 142, $5a^{VI}$) is released and mingles with the liquid of the blood. This poisonous material induces the fever which always follows the chill. The released spores may enter red corpuscles again, and in forty-eight hours in one type of malaria, and seventy-two hours in another, form spores once more.

Some of the *amœbulæ* (amœba-like stages) of the parasite have a different history. While most of them in the red corpuscles of a person go on reproducing non-sexually, as just described, some develop into a form which, by comparison with higher animals, we call the female cell (Fig. 142, $5c^{II}$), and others into male cells (Fig. 142, $5b^{III}$). If now the person be exposed to the bite of a mosquito of the genus Anopheles (see p. 63), the male and female cells of Plasmodium each reach their full development in the human red blood-corpuscles, as these rest in the stomach of the mosquito. Leaving the corpuscles, the two cells unite to form a worm-like cell

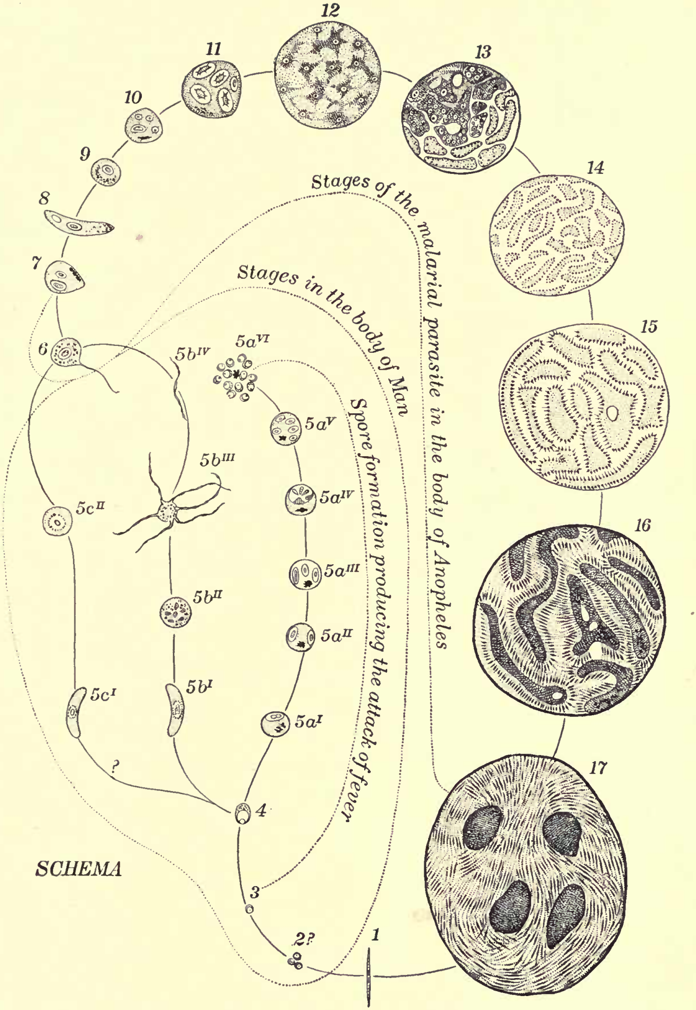


FIG. 142. Life-Cycle of Malarial Parasite. (After Grassi)

(Fig. 142, 6), which penetrates to the outer wall of the stomach of the mosquito, where it increases in size to form a large sphere (Fig. 142, 12). In a short time the sphere subdivides into countless extremely minute *blasts* (Fig. 142, 17, 1). These make their way through the body-cavity of the mosquito to the salivary glands. Penetrating to the interior of those glands, the blasts enter the ducts, and are carried outward and down the insect's proboscis by the saliva when the mosquito bites another person. Then in the human blood the blasts enter the red corpuscles and become amœbulæ, thus completing a cycle.

Prominent among the scientific men who since 1896 have discovered the facts of the life-history of the malarial parasite are Dr. Ross, of India, and Professor Grassi, of Italy. Upon their discoveries, and those of others, are based the numerous operations against the mosquito in the vicinity of large cities.

Paramœcium. Perhaps no member of the phylum under discussion in this chapter has been observed by more students than has the slipper-animalcule, *Paramœ'cium cauda'tum* (Fig. 143 *A*, *B*); and no member of its phylum has been so frequently made the basis of scientific discussions of cell-structure and cell-physiology. Paramœcium lives in stagnant pools of fresh water in all lands. Specimens may be obtained in countless numbers by placing a quantity of hay in a jar of ordinary water and leaving it to stand for a few weeks. The bacteria developed in the decaying hay furnish an inexhaustible food-supply for the animals.

As in Amœba, Euglena, and Plasmodium, the entire body of Paramœcium is a single cell. The cell when moving freely has a definite shape, although it changes constantly in outline, owing to the fact that the irregularities in the body are whirled into view as the animal swims along in a slender spiral path.

Paramœcium is about .2 mm. ($\frac{1}{125}$ inch) in length. The anterior end is rounded and the posterior end pointed. Right and left sides are, as indicated in the figures, determined by the position of the mouth (Fig. 143, 2), which is on a surface called ventral. The entire surface of the ectoplasm is covered with great numbers of short, hair-like structures, called *cilia* (Fig. 143, 1). The cilia are the organs of locomotion. Their customary manner of working is to wave backward toward the posterior end, propelling the animal forward, but they may also wave so as to send the body along with the pointed end forward. A few cilia somewhat longer than the others lie in the groove that leads diagonally across the ventral surface to the mouth. Their function is to carry the food down the short gullet into the endoplasm.

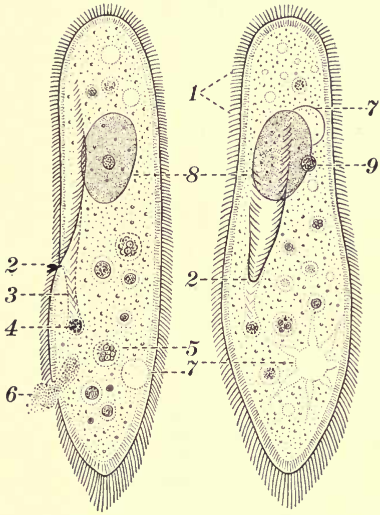


FIG. 143. Paramœcium. Much enlarged

A, left side; B, ventral surface; 1, cilia; 2, mouth; 3, gullet; 4, food-vacuole forming; 5, food-vacuole in cytoplasm; 6, anus; 7, contractile vacuole; 8, macronucleus; 9, micronucleus

(From Sedgwick and Wilson's *General Biology*)

The endoplasm, which, as already explained, is that portion of the cytoplasm lying between the nucleus and the outside layer of ectoplasm, is soft and semifluid. Food is passed into it by the *gullet* (Fig. 143, 3), and immediately begins to float away from that point, surrounded by a little drop of water. These masses are called *food-vacuoles* (Fig. 143, 4, 5).

While the current in the cell-protoplasm is carrying the food-vacuoles around, digestive fluid formed by the protoplasm is breaking up the food, liquefying, and changing it chemically for the process of assimilation or building up into protoplasm. The indigestible particles are discharged from the cell by a small opening, the *anus* (Fig. 143, 6). The waste derived from the food and protoplasm that is used up in the work of the animal is probably discharged in the form of liquid from two special organs, one near either end at the dorsal surface. These are *contractile vacuoles* (Fig. 143, 7). It is supposed that the liquid waste when formed, flows through the protoplasm along somewhat definite channels, to the point where it collects in a gradually increasing vacuole. Soon the maximum size is attained, and the vacuole bursts at the surface, the waste pouring into the water outside. The two contractile vacuoles alternate in contracting.

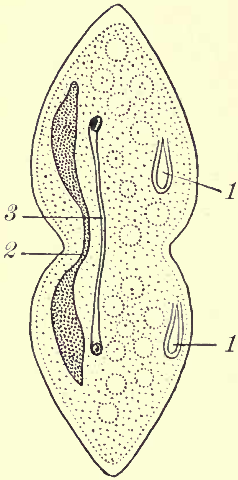


FIG. 144. Paramœcium dividing. Much enlarged

1, mouth and gullet; 2, macronucleus dividing; 3, micronucleus dividing

(From Sedgwick and Wilson's *General Biology*)

Paramœcium has two nuclei; the large one is called the *macronucleus* (Fig. 143, 8), and the small one the *micronucleus* (Fig. 143, 9). The macronucleus is thought to be the seat of the general activities of the cell, while the micronucleus is the seat of the important process of reproduction.

The theory that reproduction by division is a phase of growth was stated in the description of Amœba. Paramœcium also divides into two equivalent cells (Fig. 144), with half the macronucleus and half the micronucleus in each, probably because the volume of the cell becomes too great to be kept alive by the organs of the relatively decreasing surface. As many as three or four generations of Paramœcia may be produced in a single day. The frequency of division of the cell depends upon the kind and abundance of food obtainable, and also upon a process known as *conjugation* (Fig. 145). This complicated process was worked out in great detail in 1888 by Maupas, a French librarian, who in his spare time studied the life-history of Paramœcium and other unicellular organisms.

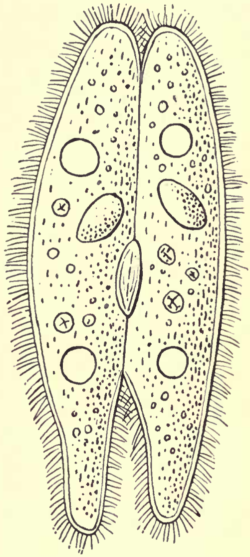


FIG. 145. Paramœcia conjugating. Much enlarged. (After Saville Kent)

In conjugation two Paramœcia unite temporarily in the manner indicated in the figure. A fraction of the micronucleus of each passes through the two contiguous layers of ectoplasm and unites with a similar fraction in the other animal. When this and certain other less essential phenomena have taken place, the individuals separate and continue the process of transverse division, but with greater frequency than before. Maupas interpreted conjugation as a process of *rejuvenescence*, or renewing the youth, through which these organisms, being exhausted by a long series of divisions, could regain their vitality, thus preventing the extermination of the race. It has been pointed out by some zoölogists that conjugation in unicellular organisms has many points of resemblance with the union of egg and spermatozoön in the higher animals. We may therefore speak of conjugation as sexual reproduction, to distinguish it from the non-sexual reproduction by division.

Some interesting experiments bearing on the problem of conjugation in Paramœcium were carried out in the years 1901 and 1902 by Professor G. N. Calkins, of Columbia University. He found that as the generations approached ninety to one hundred and seventy in number, the individuals become smaller in size and appear to lose some property in their protoplasm. He was able to "renew the youth" of his series of animals by artificial means, — twice by change of food, once by mechanical agitation, and once by a rise in temperature. After each stimulation the Paramœcia divided frequently, and in other respects imitated the phenomena subsequent to conjugation.

Results strikingly similar to these have been obtained by Professor Jacques Loeb, of the University of California, in stimulating by mechanical and chemical means the eggs of sea-urchins to develop to advanced stages. The term "artificial parthenogenesis" (see parthenogenesis, p. 34) has been used in describing the results obtained by Professor Loeb. It is interesting to notice in connection with these experiments that in the eggs of sea-urchins stimulated to develop naturally by the spermatozoön, and artificially by mechanical and chemical means, and in Paramœcium stimulated to frequent division naturally by conjugation, and artificially by mechanical and chemical means, we have a result the identity of which can be expressed under the name rejuvenescence. Although these experiments have value in interpreting the phenomena of reproduction, it is well to keep in mind the fact that the artificial method fails after a few cycles in Paramœcium, and before the end of the larval period in the sea-urchin.

When the water in which Paramœcia live shows indications of drying up, the animals encyst themselves by secreting a film of gelatinous substance from their ectoplasm. The encysted animal retains its usual form, and remains inactive until it is brought into water again.

Unicellular organisms have long been objects of profound study for biologists and psychologists. The biologists recognize in them the morphological unit of structure, identical in important details with the unit of structure in the tissues of all animals as well as all plants, but differing from the tissue-cells in the fact that the latter have only one chief function to perform, whereas unicellular organisms carry out all the processes of living in one small bit of protoplasm,—the single cell. Psychologists look to these organisms for the beginning of that phase of mind called consciousness, one evidence of which we see in the ability of ourselves and other animals to choose a course of action. As a matter of fact, we have no way of knowing whether unicellular organisms are conscious or not. According to Professor Jennings, these organisms, as well as others, manifest complicated internal physiological processes. Any external agents, as, for example, oxygen, heat, or food, which bear relation to the internal physiological processes, are concerned in the activities of the organism. If a Paramœcium comes to a place where oxygen is scarce, it will make a series of trial trips in various directions, until the internal demand for oxygen is satisfied. As the result of the needs of the organism, it is constantly on the move, but we cannot say that these movements are conscious efforts.

Definition of Protozoa (Gr. *protos*, first; *zoön*, animal). The four members of the phylum described in this chapter were selected as representatives of the four classes that make up the phylum: Amœba proteus, of the class *Sarcodi'na;* Euglena viridis, class *Mastigoph'ora;* Plasmodium malariæ, class *Sporozo'a;* and Paramœcium caudatum, class *Infuso'ria.*

Although in each class the genera differ widely, all the members of the four classes agree in being composed of single cells. Nearly all species are microscopic in size.

Reproduction is brought about by division of the cell, and never by eggs and spermatozoa.

CHAPTER XXII

THE EVOLUTION OF INVERTEBRATES AND THE ANCESTRY OF THE VERTEBRATES

> I wrote the past in characters
> Of rock and fire the scroll,
> The building in the coral sea,
> The planting of the coal.
>
> EMERSON, *Song of Nature.*

Vertebrates and Invertebrates. However various in form and structure the members of the phyla thus far discussed are, they have in common at least this negative character, that in none of them has a backbone been developed. For this reason they are collectively termed *Invertebrates* (Lat. *in*, not; *vertebratus*, vertebrate); the animals which have a backbone are called *Vertebrates.* It will be worth our while, before beginning the study of the latter, to consider some general questions of interest in connection with the evolution of the invertebrate phyla, and then to describe briefly some peculiar forms which appear to stand between the invertebrates and the vertebrates. These intermediate forms, or their ancestors, may be the immediate ancestors of the vertebrates.

THE EVOLUTION OF THE INVERTEBRATES

Sources of Information. There are, as we have seen in the chapter on insects, three sources of information which the zoölogist may draw upon, in his endeavor to discover the relationship which the animals of the past and the present evidently bear to each other, throughout the long series from the lowest to the highest. These sources of information are the geological record of species, comparative anatomy or morphology, and the embryological stages in the development of the individual. We shall consider first the record of geology, and in order to do this intelligently we shall have to begin far back, for perhaps more than any other science, geology requires of the mind of man vast sweeps of the imagination to form even faint conceptions of the illimitable processes that have brought the earth to its present state. Scarcely less awe-inspiring is the contemplation of the changes that must have taken place in living things, since life began in the ocean and on the land. Great as the time and changes were before the earth had life upon it, greater still may be the time that the processes of evolution have required to develop all the forms of life in their complexity.

The Nebular Hypothesis. The earth is one of a number of bodies called planets, which revolve about a central heated body, the sun. The planets, with their attendant moons or satellites, and a number of smaller bodies revolving about the sun in the same direction and nearly in the same plane, constitute our solar system. The nebular hypothesis is a theory which involves the suggestion of a common origin for all members of the solar system from a mass of heated gaseous material (Lat. *nebula*, cloud) in motion, which is supposed to have occupied all the space between the central sun and the orbit of the outermost planet. In the process of cooling and condensation rings of matter were formed, which later broke up into the different planets.

Archæan Time. The earliest period of the earth's geological history is termed the *Archæan Era* (Gr. *archaios*, ancient). At first all the substances, including the water which now covers three quarters of the earth's surface, were held suspended in the atmosphere, owing to the high temperature. Later there came a time when the waters condensed, and the surface, cooled still further, permitted the water to cover the rocks of the early crust entirely or in part. Stupendous volcanic upheavals must have been frequent as fire and water struggled for the mastery. During this time, of course, no life was possible. As the crust continued to cool it was upheaved and formed land. When the waters had cooled sufficiently to permit of it, life appeared, but in what form

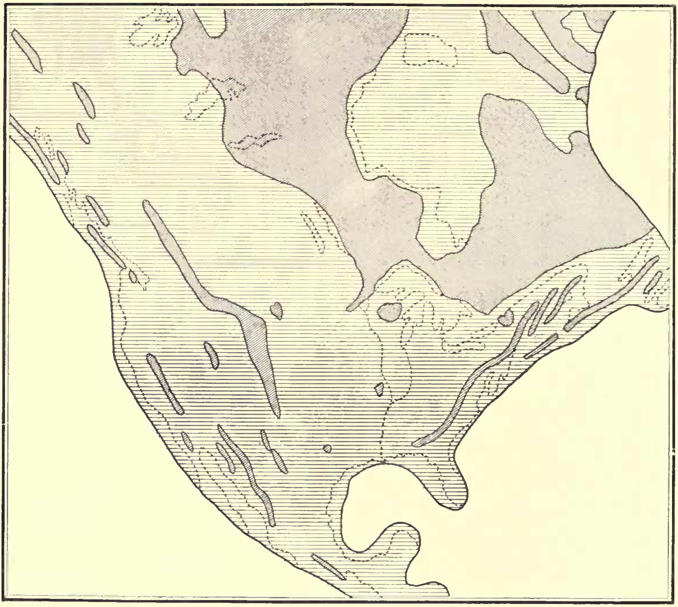


FIG. 146. North America in the Archæan Era

(From Dana's *Manual of Geology*)

we do not know. It is thought that this early life may have been plant rather than animal in its nature, since plants to-day, with the exception of the fungi (mushrooms, bacteria, etc.), feed upon mineral matter, while animals require plant or animal food. As regards the temperature at which life became possible, it is known that plants live now in the hot springs of the West in water reaching 180° F.

There is very little direct evidence to indicate the character of the life in the Archæan era, but in all probability it was of the simplest structure, like some of the single-cell organisms of to-day. Although fossil remains of that time are wanting, beds of limestone and graphite formed then, point to the existence of life, for similar beds formed in later eras are known to have been made through the agency of organ-

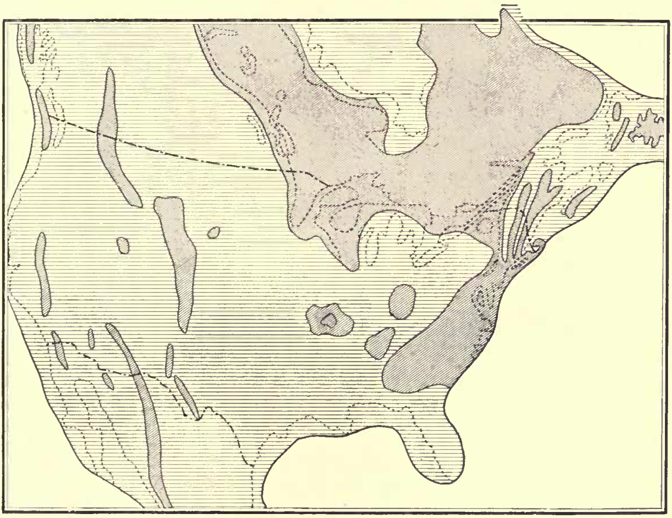


Fig. 147. North America toward the Close of the Age of Invertebrates

(From Dana's *Manual of Geology*)

isms (polyps, mollusks, etc., and plants). Fig. 146 shows the North American continent as it probably existed at the close of the Archæan era. The main body of land was a V-shaped mass lying north of the present Great Lakes and the St. Lawrence River. Archæan islands lay in the position of parts of subsequent eastern and western highlands.

The Age of Invertebrates. Following the Archæan era, several succeeding geological periods may be, for our purpose, grouped under the general term, *Age of Invertebrates*, from the predominance of these forms of life. The era was very long, undoubtedly to be reckoned in millions of years. We have no knowledge of the exact time that the different species appeared, nor of the exact length of time they existed. Neither do we know from actual specimens all the stages of evolution through which the early forms of life may have passed in coming to the form and structure in which we know their kin to-day, for the intermediate types have been lost on account of one catastrophe or another in the history of the world.

In the beginning of the era, life was marine, as far as fossil records indicate. The earliest fossils are of sponges, corals, sea-lilies or crinoids (see p. 246), worms, brachiopods (see p. 233), mollusks, and trilobites (see p. 153). Subsequently land animals made their appearance in forms like the arachnids and the insects. Before the close of the era a class of vertebrate animals, the fishes, had come into existence. The accompanying map (Fig. 147) will give an idea of the probable growth of the land area of North America during the period.

Evidence from Embryology and Morphology. Frequently the only way the zoölogist may know of the kinship of certain groups is by studying their early stages of development. Since all the animals composed of more than one cell reproduce at one time or another by means of eggs and spermatozoa, we see that all animals, however great the differences between the adults may be, are alike in being composed of one cell at the beginning of development. But in some animals the number and complexity of the changes intervening between the egg stage and the adult stage are few and simple in comparison with the changes taking place in others. All those animals which have few organs show relatively few changes in development, in comparison with those animals which have numerous, complicated organs. Hydra, for example, as morphology shows, is a very simple form compared with the earthworm. Not only has Hydra fewer organs than the earthworm, but reference to the study of development of the latter will show that the two layers of cells which constitute the entire animal Hydra represent a very early stage in the development of the earthworm.

There is an additional point of value to be observed in the comparison of Hydra and the earthworm. There are two phyla of animals that in development have two germ-layers, — Porifera and Cœlentera. All the others (except the Protozoa) have three germ-layers. The third germ-layer, the mesoderm, offers a beginning place for organs not developed in the ectoderm and endoderm, and groups of animals possessing it develop more kinds of organs than those which do not have it; that is to say, they show greater differentiation.

If we were to begin at once to arrange all animals in a regular graded series, on the basis of what we learn from morphology and from embryology, we should have a difficult task. The number of facts that it is necessary to know is so considerable that even to-day systematic zoölogists are not agreed on important details of grouping animals in a complete system of classification. Besides, the doctrine of evolution takes into account the fact that the phyla of animals have not developed in a direct line, but as branches from a previously existing stem. The whole system of animals might be represented graphically by a series of stem and branches resembling a tree; but whereas in a tree we can trace down one branch and out any other, in the diagram suggested some of the branches would not be connected with the stem at all, because the organisms which would stand in the connecting places have disappeared both in living and in fossil form.

However, we can see very clearly that the Protozoa being composed of a single cell are the lowest of all animals; and that the Porifera, with their structure showing no sign of digestive organs, muscle-cells, nerve-cells, or sense-organs, are the simplest of the many-cell animals (Metazoa). Of course we do not place the Porifera next above the Protozoa until we have weighed the facts by comparing their structure with the only other phylum that has two germ-layers. The Cœlentera have, as we recall, a gastrovascular cavity, simple muscle-cells, nerve-cells, and sense-organs.

An attempt to classify the animals that have three germ-layers in development immediately brings us into difficulties. Formerly it was the custom to place the Echinoderma near the Cœlentera because of their radiate plan of structure, but now the radial symmetry is not generally considered a factor of great significance. The old group of Vermes has been thoroughly studied in recent years, and, as indicated in Chapter XVII, it has been subdivided into five phyla by some of the best-known authorities. In the order of their increasing complexity, the phyla are Platyhelminthes, Nemathelminthes, Trochelminthes, Molluscoida, and Annulata. They are all bilaterally symmetrical animals, but only the last phylum has the body divided into somites. Because of this and other facts, the order of classification is modified by the English zoölogists Parker and Haswell by placing the Echinoderma between the Molluscoida and the Annulata. The Echinoderma have an alimentary canal separated from the body-cavity, digestive glands, a fairly well-defined blood-system, an elaborate water-vascular system, and a definite nervous system. For these reasons they are entitled to rank next to the Annulata. All members of the Annulata have the body divided into somites with unsegmented appendages. The body has a distinct alimentary canal, a complete blood-system, and a more complicated nervous system than is found in any of the phyla already mentioned. The system of nephridia also is more extended, one pair being present in every somite.

The phylum Arthropoda is pretty clearly distinct from other phyla. Its advance over the Annulata consists in the tendency of the somites to be fewer and more definite in number. The somites are grouped in two or three regions; in certain regions the somites are fused, an indication of still greater differentiation. All the appendages are segmented. The dorsal blood-vessel is more differentiated than other parts of the circulatory system, and in some classes it is a clearly defined one-chambered heart. Sense-organs, especially eyes, reach a condition of great complexity in comparison with what is found in lower phyla.

If division into somites is an indication of advance, the loss of it would seem to be an indication of degeneration, but we have no proof that the ancestors of the Mollusca had bodies which showed metamerism. Their development was evidently in a different direction from that of the Annulata and the Arthropoda. The factors which seem to place Mollusca higher in the system are greater centralization of the nervous system in a miniature "brain," and the possession of a three-chambered heart, — two auricles and one ventricle.

Invertebrate Phyla and Classes

The subjoined list of the classes discussed in the first twenty-one chapters will be of service in recalling the relative position of the phyla in the system of classification.

I. Protozoa

Class 1. Sarcodina; *example*, Amœba proteus.
Class 2. Mastigophora; *example*, Euglena viridis.
Class 3. Sporozoa; *example*, Plasmodium malariæ.
Class 4. Infusoria; *example*, Paramœcium caudatum.

II. Porifera

Class 1. Porifera; *example*, Heteromeyenia ryderi.

III. Cœlentera

Class 1. Hydrozoa; *example*, Hydra viridis.
Class 2. Scyphozoa; *example*, Aurelia flavidula.
Class 3. Actinozoa; *example*, Metridium marginatum.
Class 4. Ctenophora; *example*, Pleurobrachia rhododactyla.

IV. Platyhelminthes

Class 1. Turbellaria; *example*, Dendrocœlum lacteum.
Class 2. Trematoda; *example*, Distomum somateriæ.
Class 3. Cestoda; *example*, Tænia saginata.

V. Nemathelminthes

Class 1. Nematoda; *example*, Trichina spiralis.

VI. Trochelminthes

Class 1. Rotifera; *example*, Brachionus urceolaris.

VII. Molluscoida

Class 1. Polyzoa; *example*, Plumatella repens.
Class 2. Brachiopoda; *example*, Lingula lepidula.

VIII. Echinoderma

Class 1. Asteroidea; *example*, Asterias vulgaris.
Class 2. Ophiuroidea; *example*, Astrophyton agassizii.
Class 3. Echinoidea; *example*, Strongylocentrotus dröbachiensis.
Class 4. Holothuroidea; *example*, Cucumaria chronhjelmi.
Class 5. Crinoidea; *example*, Pentacrinus blakei.

IX. Annulata

Class 1. Chætopoda; *example*, Lumbricus terrestris.
Class 2. Hirudinea; *example*, Placobdella rugosa.

X. Arthropoda

Class 1. Crustacea; *example*, Cambarus affinis.
Class 2. Xiphosura; *example*, Limulus polyphemus.
Class 3. Arachnida; *example*, Argiope riparia.
Class 4. Myriapoda; *example*, Lithobius americanus.
Class 5. Hexapoda; *example*, Melanoplus femur-rubrum.

XI. Mollusca

Class 1. Pelecypoda; *example*, Mya arenaria.
Class 2. Gasteropoda; *example*, Helix nebulosa.
Class 3. Cephalopoda; *example*, Nautilus pompilius.

Probable Ancestors of the Vertebrates

The Lancelet. It is always important to find, if possible, connecting links between large and seemingly distinct groups of animals. The words "invertebrate" and "vertebrate" were once thought to be terms which together included all animals; but zoölogists have discovered several animals which are neither vertebrate nor invertebrate in the usual sense of the words.

The first of the three animals to be described in this section of the chapter is a vertebrate of a very simple type.

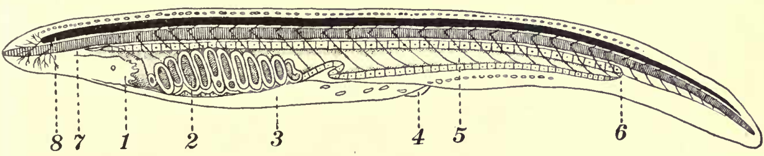


Fig. 148. The Lancelet. × 2. (After Kowalevsky)

1, mouth; 2, gill-slits; 3, atrium; 4, atrial pore; 5, intestine; 6, anus; 7, notochord; 8, nerve-cord

The lancelet (*Amphiox'us lanceola'tus*, Fig. 148) is a fish-like animal about two inches long. It lives almost imbedded in the sand at the sea-bottom in Chesapeake Bay and in other warm ocean waters.

The *mouth* (Fig. 148, 1) of the lancelet opens into a long *pharynx*, which has many pairs of *gill-slits* (Fig. 148, 2). When water and food pass in at the mouth, the water passes through the gill-slits, giving up oxygen to the blood in the gills, and then passes into a chamber partially surrounding the pharynx, called the *atrium* (Fig. 148, 3), and to the outside by the *atrial pore* (Fig. 148, 4); the food goes down the *intestine* (Fig. 148, 5).

Immediately above the intestine is the structure which corresponds in position to the backbone of higher animals; it is called the *notochord* (Fig. 148, 7). The notochord is soft throughout life, but it is sufficiently strong to act as a support-

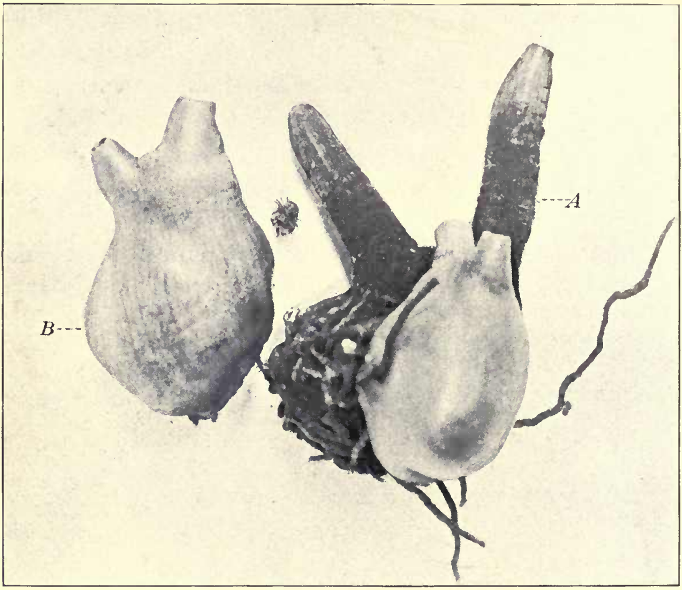


Fig. 149. Photograph of Living Tunicates. Natural size
A, Styela stimpsoni; B, Cynthia haustor

ing skeleton for the body. Parallel with the notochord and above it, is the *spinal cord* (Fig. 148, 8) lying near the dorsal wall. The characteristics of structure which make Amphioxus a vertebrate are the presence of gill-slits, a notochord above the intestine, and a spinal cord dorsal to the notochord.

The Sea-Squirt. As far as outward appearance indicates the sea-squirts, *Sty'ela stimpson'i* and *Cyn'thia haus'tor* (Fig. 149, *A* and *B*), have nothing in common with vertebrates. Sea-squirts live attached to rocks and wharves, and once attached never leave the place. The body is covered with a tough coat or tunic, which gives the class its name, *Tunica'ta*. The food and oxygen are drawn through the opening in the upper tube, and the excess water and wastes are discharged by the lower tube. There is a pharynx with gill-openings, and a nervous system, but there is no indication of a notochord.

The adult tunicate exhibits a lower degree of organization than the larva. The larva (Fig. 150) has very much the form of a frog-tadpole, and it swims about. Its locomotor organ is a fin-like tail (Fig. 150, 12). As long as the animal remains a larva it has structures which indicate vertebrate relationship. Extending through the middle of the tail is a *notochord* (Fig. 150, 6), which is evidently a supporting organ. Dorsal to the notochord is the *nerve-cord* (Fig. 150, 7). Below the notochord is the *alimentary canal* (Fig. 150, 3), and near by are the beginnings of the *gills*, with openings (Fig. 150, 2) which, however, are not gill-slits. When the larva reaches a certain stage of development, it fastens itself by *adhesive papillæ* (Fig. 150, 11)

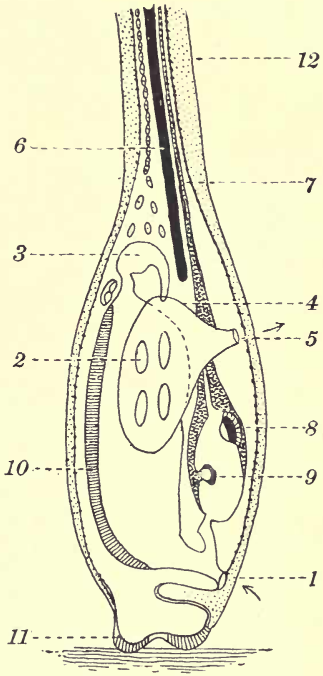


FIG. 150. Larva of Tunicate. Much enlarged. (After Herdman)

1, incurrent opening; 2, gill-openings; 3, intestine; 4, anus; 5, excurrent opening; 6, notochord; 7, nerve-cord; 8, eye; 9, otocyst; 10, endostyle; 11, adhesive papillæ; 12, portion of tail to some fixed object. Then begins the process of degeneration of all distinctly vertebrate structures; the tail is absorbed, the notochord also disappears, and the nerve-cord changes form. If it were not for what is known of the larva, the vertebrate relationship of tunicates would never be suspected.

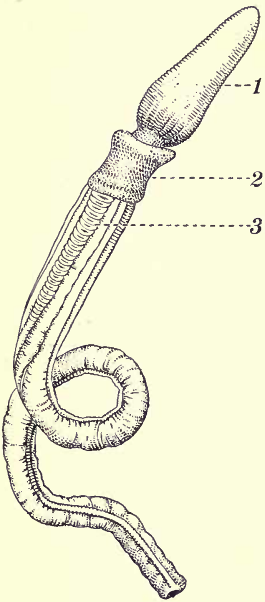


FIG. 151. Acorn-Tongue Worm. Enlarged. (After A. Agassiz)

1, proboscis; 2, collar; 3, gill-slits

The Acorn-Tongue Worm. Some zoölogists have supposed that the ancestors of the vertebrates were worm-like animals. The reasons for that supposition are based chiefly on the structure of the acorn-tongue worm, *Balanoglos'sus* (Fig. 151). This animal is found in the sand of seashores. It has a *proboscis* (Fig. 151, 1) with a collar-like band (Fig. 151, 2) at the base, both organs together somewhat resembling an acorn in its cup.

The mouth, at the base of the proboscis, opens into a pharynx from which many pairs of *gill-slits* (Fig. 151, 3) open to the exterior. There is a *dorsal nerve-cord* and a *ventral nerve-cord*. A notochord-like structure has been found extending into the middle of the proboscis. Many zoölogists express doubt concerning this organ, and no investigator seems to be positive of its notochordal structure. If the main nerve-cords were limited to one above the intestine, that would clearly be a vertebrate characteristic; but with one above and one below, it is neither definitely vertebrate or invertebrate, and hence possibly an intermediate form. The gill-slits have the position and form of those in Amphioxus.

CHAPTER XXIII

THE YELLOW PERCH

Give me some observations and directions concerning the *Pearch* for they say he is both a very good and a bold biting fish, and I would fain learne to fish for him. —Izaak Walton, *The Complete Angler*.

Habitat and Distribution. Brilliant in coloration, abundant and easy of capture, and possessing a firm, white flesh of delicate flavor, it is no wonder that the yellow perch (*Per'ca flaves'cens*, Fig. 152) is one of the best known of the fresh-

Fig. 152. Photograph of Yellow Perch. Reduced

(From Jordan and Evermann's *American Food and Game Fishes*)

water fishes of the United States. Though found in streams, especially in those with quiet reaches of water, the yellow perch is more truly a creature of ponds and lakes. There it prefers a pebbly or sandy bottom. Its range extends from Labrador to Georgia in the fresh-water rivers and the lakes along the Atlantic coast, and westward in the region of the Great Lakes and upper Mississippi valley. Though originally absent from the far West, it has recently been introduced with success into the lakes of Washington, Oregon, and California. In structure and habits our yellow perch very closely resembles the perch of Europe, referred to in the quotation at the head of this chapter, and by some authors it is considered to be identical with the latter species.

External Structure. The body of the perch is elongate, slightly compressed from side to side, and tapers toward both ends. Three divisions are apparent, the *head*, *trunk*, and *tail;* several appendages, the *fins*, are attached to the body. The covering is a smooth *skin*, containing pigment cells, to which the colors are due, and glands which secrete mucus. Within pouches in this skin are transparent *scales*, which overlap, like the shingles on the roof of a house, and form a coat of mail, incasing the fish from head to tail. Along a clearly defined *lateral line* the scales are somewhat modified, and beneath them are sense-organs the functions of which have been variously stated. Professor G. H. Parker considers that these organs are sensitive to mechanical jars of a low rate of frequency, thus standing between organs of touch proper, and those of hearing.

At the anterior end of the head are the *jaws*, armed with teeth for seizing food. The *eyes* have no eyelids. Just in front of the eyes are the *nostrils*, two on either side. They have no communication with the mouth. Behind the eyes, on each side of the body, is a movable flap called the *operculum*, beneath which are the red comb-like gills.

There are five fins, three unpaired and two in pairs. Of the unpaired fins those on the back are called the *dorsal* fins, the one on the under side the *anal* fin, and the one at the tail the *caudal* fin. The more anterior of the paired fins are the *pectoral* fins; the more posterior and lower, the *ventral* or *pelvic* fins. The fins are supported by *fin-rays* of two sorts, the one hard, unsegmented, and unbranched (Fig. 153, 1); the other soft, segmented, and branched (Fig. 153, 2).

The Digestive System. The *mouth* is large. *Teeth* are borne not only on the jaws but also on the roof of the mouth (Fig. 153, 6, 7, 9). On the ventral surface of the mouth is a rather large, fleshy *tongue* (Fig. 153, 8). Behind the tongue is the *pharynx* (Fig. 153, 10), with gill-slits on both sides, which allow water from the mouth to pass into the gill-chamber. From the pharynx a short *œsophagus* leads to the *stomach* (Fig. 153, 14). Several *pyloric cæca* (Fig. 153, 15) open into the *intestine* (Fig. 153, 16), increasing its absorbing and secreting surface. The intestine ends ventrally at the *anal opening* anterior to the anal fin (Fig. 153, 4). The liver-secretion, called bile, is stored in a *gall-bladder* (Fig. 153, 12) attached to the posterior surface of the *liver* (Fig. 153, 11), and finds its way into the alimentary canal through the *bile-duct* (Fig. 153, 13). Close to the alimentary canal, but not opening into it, is a bright red organ called the *spleen* (Fig. 153, 20), the function of which is not positively known.

The Circulatory, Respiratory, and Excretory Systems. The *heart* is placed in a large *pericardial cavity*, the posterior wall of which forms a thin membrane separating the heart from the other organs of the body-cavity. Two divisions to the heart may be clearly distinguished, an *auricle* (Fig. 153, 21) and a *ventricle* (Fig. 153, 22). The blood, driven from the heart by the contraction of the ventricle, is forced through an *artery* (the *aorta*) with a bulbous base (*bulbus aortæ*, Fig. 153, 23) to the gills, where it is aërated. After aëration the blood is collected into a dorsal artery, which carries it through the body, giving off branches to the various organs. In the *capillaries* of the different organs it gives up its oxygen, collects waste products, and makes its way through the *veins* to the auricle, whence it enters the ventricle to repeat its circulation. Valves in the heart and in the course of the venous circulation prevent the backward flow of the blood. In addition to the blood, a white fluid (lymph) circulates through the body in vessels called *lymphatics*. The function of the lymph is supplementary to that of the blood.

The principal organs of respiration are the *gills*, eight in number, four on either side. Each gill consists of a bony *arch*, on the anterior surface of which are teeth-like *gill-rakers;* on the posterior surface are the delicate *gill-filaments*. In this position the filaments are constantly bathed by a current of water, which passes from the mouth-cavity out beneath the operculum. In the dorsal part of the body-cavity is a large *air-bladder* (Fig. 153, 19). In the lining of the wall of the air-bladder is a network of blood-vessels, grouped into gland-like "red bodies." By the absorption and formation of gas by these blood-vessels the weight of the fish can be maintained nearly equal to that of the water it displaces. The air-bladder is probably useful also as a reservoir of air, for it has been found that in a perch suffocated in stagnant water the oxygen in the air-bladder, which normally amounts to about one fifth of the volume of the inclosed gas, had been entirely absorbed and replaced by carbon dioxide and nitrogen. In some fishes the air-bladder communicates with the alimentary canal by means of a tube called the *pneumatic duct*. In the perch this duct is present in early life, but it soon closes, remaining, however, as a fibrous cord (Fig. 153, 18).

The perch, like other fishes, is usually spoken of as cold-blooded, since its body-temperature is little above that of the surrounding medium. Compared with the higher vertebrates, the birds, for example, very little oxygen is required for respiration, and the circulation is comparatively slow.

The principal organs of excretion are the *kidneys* (Fig. 153, 24), placed just above the air-bladder and below the back-bone. From the kidneys two tubes, the *ureters* (Fig. 153, 25), lead,

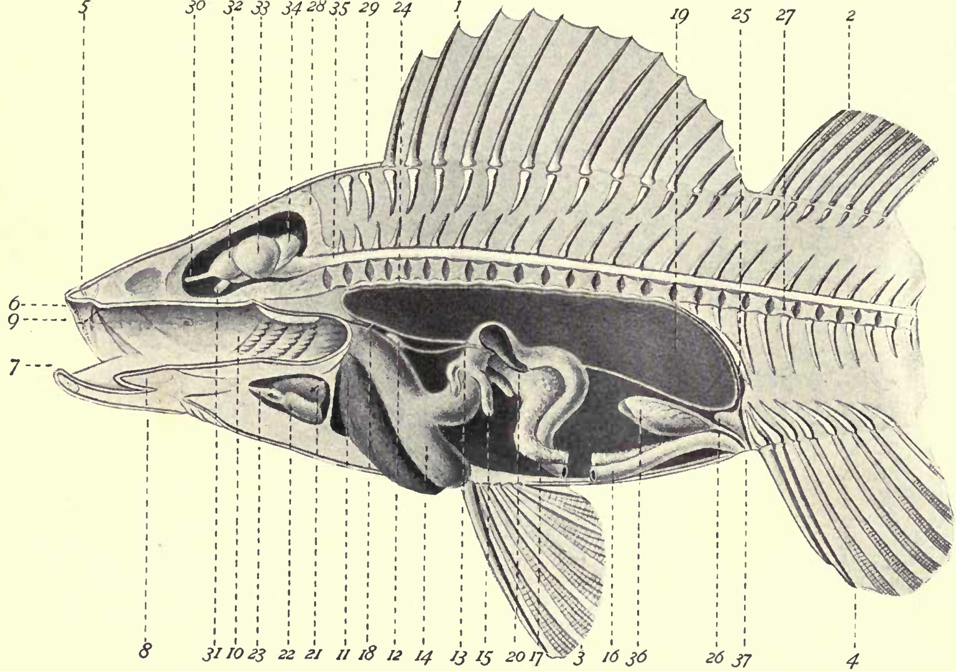


Fig. 153. Dissection of the Yellow Perch (*Perca flavescens*). Reduced

1, hard spine; 2, soft ray; 3, ventral fin; 4, anal fin; 5, nostril; 6, teeth in upper jaw; 7, teeth in lower jaw; 8, tongue; 9, teeth on roof of mouth; 10, pharynx; 11, liver; 12, gall-bladder; 13, bile-duct; 14, stomach; 15, pyloric cæcum; 16, intestine; 17, fat-mass; 18, cord leading from air-bladder to alimentary canal; 19, air-bladder; 20, spleen; 21, auricle of heart; 22, ventricle of heart; 23, bulbus aortæ; 24, kidney; 25, ureter; 26, urinary bladder; 27, vertebra; 28, cranium; 29, interspinal bone; 30, olfactory tract; 31, optic nerve; 32, cerebrum; 33, optic lobes; 34, cerebellum; 35, spinal cord; 36, ovary; 37, urinogenital opening after union, to the *urinary bladder* (Fig. 153, 26). The contents of the urinary bladder are carried to the surface of the body at the *urinogenital opening* (Fig. 153, 37), just posterior to the anal opening.

The Skeletal System. So far in our study of the animal kingdom the skeletal, or protecting and supporting, parts have been found chiefly on the outside; in the fish there is a well-developed internal skeleton formed of bones composed largely of phosphate of lime. Running from head to tail through the body is the back-bone or *vertebral column*, consisting of a number of separate bones called *vertebræ* (Fig. 153, 27), and continued into a brain-case or *cranium* (Fig. 153, 28) at the anterior end. Bones also form the foundation of the upper and lower jaws, and support the gills and tongue. Attached to the back-bone are a number of *ribs* which inclose and protect the organs of the body-cavity. A row of small bones (*interspinals*, Fig. 153, 29) supports the unpaired fins. The pectoral and ventral fins are each supported by a framework of bones forming respectively a *shoulder-girdle* and a *hip* or *pelvic girdle*.

The Nervous and Muscular Systems. Four divisions are quite clearly marked in the *brain*, — the *cerebrum* (Fig. 153, 32); the two large rounded *optic lobes* (Fig. 153, 33); the medially and dorsally placed *cerebellum* (Fig. 153, 34); and the *medulla oblongata*, the latter tapering posteriorly into the *spinal cord* (see Fig. 153, where the medulla is shown though not numbered). Anteriorly the brain is prolonged into the *olfactory tracts* (Fig. 153, 30), which communicate with the nostrils; *nerves* extend to the different sense-organs and to the various parts of the body.

The *ears* of the perch consist of two closed cavities on opposite sides of the cranium, containing concretions of carbonate of lime, called *otoliths*, or ear-stones. There has been some question in the past as to whether fishes could hear, but recent experiments seem to show that some, at least, are capable of appreciating sound-vibrations. The ears also serve as organs of equilibration, by aid of which the fish is able to maintain its balance. The sense of touch is located in the skin generally, and in the lateral-line organs. The sense of taste is not greatly developed in the perch, and the eyes are not adapted for vision at any great distance. The organ of smell of fishes is peculiar among vertebrates in that it has no connection with the respiratory system.

The muscular system consists principally of a long, thick *muscle* on either side, stretching from head to tail. In the young fish this muscle is divided into muscular segments extending vertically and corresponding in number with the vertebræ. As the young fish begins active existence the muscle-segments are bent and twisted so that for a portion of their extent they seem to run zigzag.

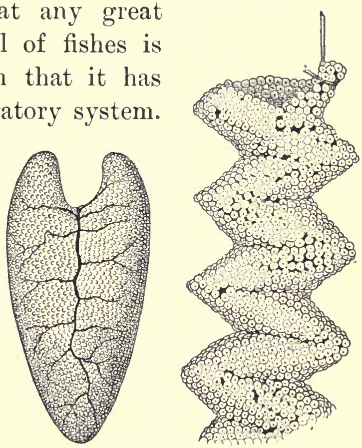


Fig. 154. Eggs of Perch before and after Egg-Laying. Reduced

(From *Bulletin United States Fish Commission*)

The Reproductive System. Both the *ovary* of the female (Fig. 153, 36) and the *spermaries* of the male are of large size in the mature perch. They open on to the surface at the urinogenital opening (Fig. 153, 37).

Development. Early in the spring the adult perch, which have spent the winter in the deepest waters of ponds or lakes, often without feeding very much, draw toward the shore. The colors, especially on the males, begin to brighten, till an adult perch in the full glory of his breeding colors is one of the most beautiful objects in his domain. The time of spawning varies with the climate; in the South it begins as early as March; in New England, in May. The eggs are laid in shallow water in a ribbon-like mass, which, after absorption of water, is sometimes six or seven feet long and two inches in diameter. This great mass, which contains thousands of eggs (over a hundred thousand have been counted in a two-pound perch), is fertilized by the male emitting his sperm (milt) over it. The eggs form a large part of the food of other fishes and aquatic birds, and were it not for their great numbers few would ever hatch. In from two to four weeks, depending on the temperature, the young perch hatches from the egg, at first with the yolk-sac attached to the ventral surface (compare Fig. 155). After absorption of the yolk-sac, which soon occurs, the young perch differs from the adult chiefly in its smaller size and lighter color, and in the relatively greater size of head and eyes as compared with the rest of the body.

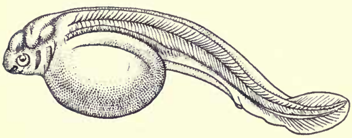


FIG. 155. Young Sturgeon with Yolk-Sac. Enlarged. (After Ryder)

Relation to Environment. The whole organization of the perch marks it at once as one of the predatory type of animals, — those which hunt their food and depend upon their superior strength or agility to obtain it. As Izaak Walton long ago said of its European relative, the yellow perch is "one of the fishes of prey that, like the *Pike* and *Trout*, carries his teeth in his mouth, not in his throat, and dare venture to kill and devour another fish." The shape of the body is precisely that which offers least resistance to motion in the water. The strong lateral muscles afford an economical method of applying power for propulsion to the caudal fin, which, by a slight lateral motion, drives the fish forcibly forward. Lateral and median fins assist in maintaining equilibrium, in steering, and in raising and lowering the fish in the water.

The colors of most fishes are protective in their nature, and the perch is no exception to this general rule. From above, the olivaceous back is with difficulty distinguished from the water itself or the bottom below; from beneath, the white under parts are colored like the surface of the water or the atmosphere above. The mottled sides also serve to render the perch less conspicuous in an environment of lights and shadows among weeds and rocks on the bottom. It has been noted that in some instances where perch live both in a large lake and in its tributaries, as in Lake Michigan and the rivers which flow into it, the lake fish have a tendency to lighter general coloration and to disappearance of the dark vertical bands. It has been suggested that this difference in color is due, in part at least, to the smaller amount of light, combined with the absence of dark lurking-places.

The study of the mental organization of the perch is beset with many difficulties, though it is of the greatest interest for the light it may throw on problems connected with the mental life of the higher animals; for the perch is a member of the class of fishes, one of the oldest and most generalized of the vertebrates, to which division man himself belongs. Perch are able to learn, and they profit by experience, even though the line along which education can take place is very narrow. In order to test their capacity to learn, two adult perch were kept in an aquarium in which a glass partition was placed several times a week for a period of about a month. Live minnows were introduced on the opposite side of the partition at the times of experimentation. Of course the perch bumped their noses against the glass in a vain attempt to get at the food temptingly displayed at so short a distance. After they had become accustomed to this reaction, whenever they made a movement in the direction of the minnows, the glass partition was removed, and they were watched to see if by their actions they seemed to recall the effect which had invariably followed a movement in the direction of the minnows. On the whole, the observer concluded that the perch showed strong symptoms of having learned to appreciate the presence of an obstacle, for neither fish made a move in the direction of the minnows when the partition was first removed. The same observer noted that perch are very imitative, a series of motions on the part of one being very likely to be performed by others. This is probably of use in connection with their gregarious life, where the "school" is kept together by each fish watching and following the others.

Sight is probably the best developed sense, though, as already stated, the eyes are not adapted to vision at a great distance. To test the power of sight discrimination, the observer quoted above dropped into the aquarium pieces of wireworms (larvæ of click-beetles) alternately with similar bits of earthworms. Nearly every time one or more of the bits of wireworm were seized by the perch, only to be dropped a moment later. The fishes did not seem to make any permanent association between the appearance of the wireworm and its inedible character.

Perhaps the clearest way to picture the limitations in the mental organization of a fish is to sum up, as Professor Sanford does, some characters in which the fish differs from man. "No fish is ever conscious of himself; he never thinks of himself as doing this or that, or feeling in this way or that way. The whole direction of his mind is outward. He has no language and so cannot think in verbal terms; he never names anything; he never talks to himself. As Huxley says of the crayfish, he 'has nothing to say to himself or any one else.' He does not reflect; he makes no generalizations. All his thinking is in the present and in concrete terms. He has no voluntary attention, no volition in the true sense, no self-control."

The food of the young perch at first consists entirely of small, delicate crustaceans, such as Cyclops and its allies; from the time the perch are about an inch and a half in length they begin to add insects to the bill of fare. Adult perch have a still more varied diet, consisting of the larger crustaceans, mollusks, and other fishes. The young are gregarious, and those of about the same size tend to keep together, so that every farmer boy knows his chances of catching "a big one" are small indeed when he has his hook in a swarm of little fishes. He has, however, this consolation, — that the supply of the one size is likely to last; for

> Perch, like the Tartar clans, in troops remove,
> And, urged by famine or by pleasure, rove ;
> But if one prisoner, as in war, you seize,
> You 'll prosper, master of the camp, with ease
> For, like the wicked, unalarmed they view
> Their fellows perish, and their path pursue.
>
> OPPIAN, *Halieutica.*

CHAPTER XXIV

THE ALLIES OF THE PERCH: PISCES

Halcyon prophecies come to pass
In the haunts of bream and bass.
MAURICE THOMPSON.

Definition of Pisces (Lat. *piscis*, a fish). The perch is a member of the class *Pis'ces*. Fishes are cold-blooded vertebrates, adapted to life in the water. In the lower forms the notochord persists as a continuous rod; in the higher fishes it is replaced by the vertebræ. The body is covered with a skin, in which are numerous mucus-glands. Scales are usually present, set in pouches in the skin. In the great majority of forms gills are the only organs of respiration. Locomotion is usually effected by means of fins. With very few exceptions, fishes lay eggs from which the young are hatched; that is, they are oviparous.

There is a remarkable uniformity of type in the class when the number of species (about fifteen thousand) and the length of time they have been in existence is considered. Professor Dean, of Columbia University, says: "The evolution of fishes has been confined to a noteworthy degree within rigid and unshifting bounds; their living medium, with its mechanical effects upon fish forms and structures, has for ages been almost constant in its conditions; its changes of temperature and currents have rarely been more than of local importance, and have influenced but little the survival of genera and species widely distributed; its changes, moreover, in the normal supply of food organisms cannot be looked upon as noteworthy."

We shall consider three of the four groups into which the fishes are usually divided.

Sharks and Rays. The sharks and rays, or *Elasmobran'chii* (Gr. *elasmos*, plate; *branchia*, gills), are fishes with a cartilaginous skeleton and with gills which communicate with the surface by several openings, instead of being covered by an operculum, as in the perch. The skin is roughened by small tubercles, which, when closely set, form shagreen, used in the arts for polishing woods and for ornamental work. The tail is usually unequally lobed, the dorsal division being the larger.

The sharks (Fig. 156) are, with the exception of one species found in Lake Nicaragua, marine animals, and are developed

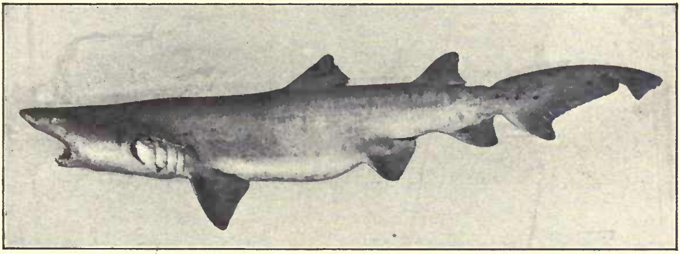


FIG. 156. Photograph of Shark. (American Museum of Natural History)

to the greatest extent in the tropics. The rays, or skates, are more flattened forms, adapted to a life on the bottom of the sea, which they often resemble in color. Fig. 157 shows a species common on the North Atlantic coast, which grows to be about two feet in length. The most famous of the rays are the torpedoes, so called from their power of giving an electric shock. About fifteen species of torpedoes are known, of which one is sometimes found on the eastern coast of the United States.

Bony Fishes. The bony fishes, or *Teleos'tomi* (Gr. *teleos*, complete or perfect; *stoma*, mouth), in the higher forms, of which the perch is an example, have the skeleton ossified (converted into bone) and the body usually covered with scales; in the lower forms the body may be covered with bony plates, and the skeleton may be hardly more ossified than in the group which has just been considered. In all teleostomes, however, the gills open beneath a protecting operculum. The order comprises ninety-five per cent of all known fishes.

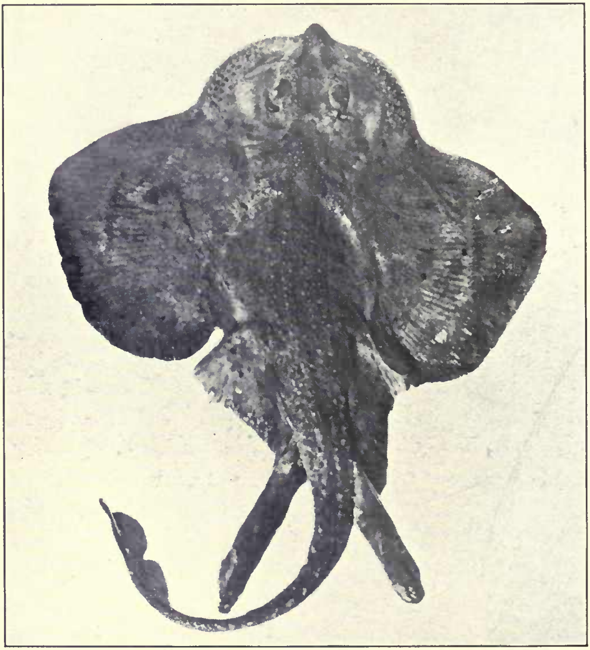


Fig. 157. Photograph of Skate

The garpikes of American waters illustrate one type of body-covering, consisting of bony, enameled, closely set plates, which form a complete coat of armor. The sturgeons (Fig. 158) illustrate another type in which the armor is greatly reduced, the teeth absent, and the animals adapted to bottom-feeding by the development of a beak, and by barbels for feeling for their food in the mud. Sturgeons are found in

Europe as well as in the United States and Canada. One of the European species grows to be over twenty feet long.

The remaining bony fishes have fully ossified skeletons. The eels are forms in which the body is greatly elongated and the scales reduced to almost invisible rudiments. Locomotion is effected by snake-like movements of the body. The common eel (*Anguil'la chrys'ypa*) of North America is found along the Atlantic coast from Newfoundland to Central America, and in most streams and ponds in the eastern states

Fig. 158. Photograph of Sturgeon
(From Jordan and Evermann's *American Food and Game Fishes*)

which are accessible from the sea. The young are hatched on mud-banks in the Atlantic Ocean, often near the mouth of a river. The eggs are laid in the fall, and the young, at the beginning of the second spring, find their way in countless numbers up the various streams, where they complete their development and return to the sea to spawn. After providing for the new generation the adult eels die, never returning to fresh water. The number of young produced has been estimated, in the case of an eel thirty-two inches long, to be 10,700,000. Eels may grow to be four feet long.

The Atlantic salmon (*Sal'mo sa'lar*) is a well-known food-fish found on the coasts of both Europe and America. Unlike the eel, the salmon spends most of its life in the sea, visiting the fresh water, however, to spawn, — in this ascent leaping waterfalls which may be in its way. Leaps of over twelve feet have been recorded. Several allied species of salmon are extensively canned on the Pacific coast.

The flatfishes (including among other fishes the flounders and halibuts) are a family of compressed fishes, dark on one side and light on the other, which lie on the light side on

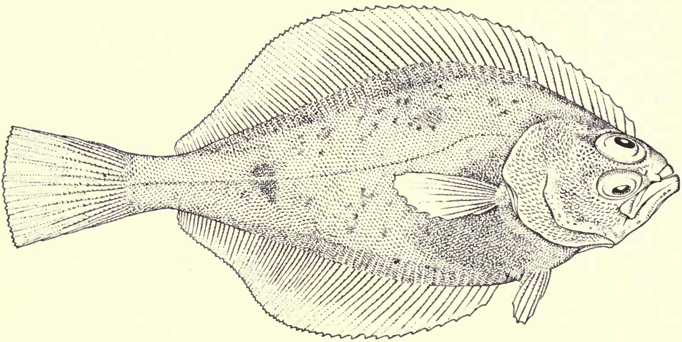


Fig. 159. Flatfish

(From *Report of Fur-Seal Investigations*)

the bottom of the sea (Fig. 159). When thus placed the dark surface is protectively colored and the eyes are both on the upper side, which is sometimes the right side and sometimes the left side of the body. When they are hatched they have an eye on either side and they swim like other fishes, though with a slight leaning to one side, which becomes more and more marked as they develop, till they finally turn entirely over. The eye on the light side has meanwhile worked its way slowly round on to the dark side, where it remains with its fellow, looking upward when the fish lies on the bottom.

The absence of coloring matter on the side which is in contact with the bottom seems to be due to the fact that little or no light reaches it, for when a number of young flounders were placed, under experimentation by Professor Cunningham of England, so that the under side was illuminated by a mirror for four months, nearly all the specimens developed pigment on the skin of that surface.

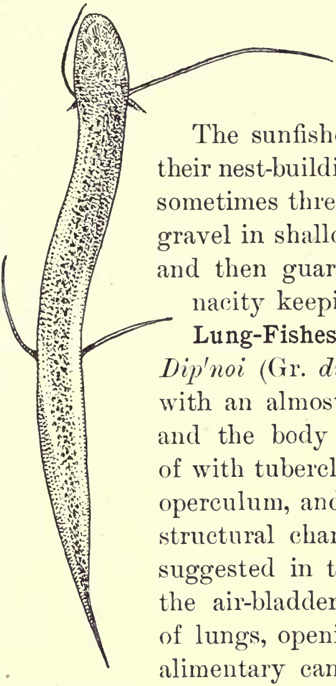


FIG. 160. Lung-Fish. (After Dean)

The sunfishes are interesting on account of their nest-building habits. They scoop out a space, sometimes three feet across, in the clear sand or gravel in shallow water. Here the eggs are laid, and then guarded by both parents, their pugnacity keeping larger fishes at a distance.

Lung-Fishes. The lung-fishes (Fig. 160), or *Dip'noi* (Gr. *di*, two; *pneo*, breathe), are fishes with an almost entirely cartilaginous skeleton, and the body is covered with scales instead of with tubercles. The gills are covered by an operculum, and the tail tapers to a point. The structural character of the greatest interest is suggested in their common name; in place of the air-bladder there is a true lung, or pair of lungs, opening from the ventral side of the alimentary canal. Dipnoans differ from other fishes, too, in the fact that the heart is incompletely divided into three chambers. These animals are interesting as the possible ancestors of the toads, frogs, and their allies, which we shall consider later. Though numerous in earlier times, there are but three genera now in existence, one each in the rivers of Queensland (in Australia), Brazil, and tropical Africa. "The Australian species inhabits rivers which at certain seasons become fetid with decaying vegetation, and during the time it breathes air." The African and South American species "bury themselves in mud during the dry season, a necessary precaution, since they inhabit swamps which dry up."

Economic Importance of Fishes. The value to a people of an abundant and cheap fish-supply cannot be overestimated. Recognizing its importance, the United States government has long maintained a Commission of Fish and Fisheries (the name of which has been changed recently to Bureau of Fisheries), which has been active along both practical and scientific lines. Among the subjects which are considered by the bureau are the resources of our inland and coastal waters, the geographical distribution of the economically important fishes inhabiting them, and the study of the natural history of fishes, their enemies, diseases, and the remedies therefor. It has also made statistical researches into the condition and commercial value of the fishing industries of the United States, and the methods employed in these industries; and, perhaps the most important of all, it has carried on the artificial propagation and distribution of valuable species. Thus, during the year ending June 30, 1901, 1,173,833,400 fishes and eggs were distributed to different parts of the United States, the principal species being shad, salmon, lake-trout, whitefish, pike, perch, lake-herring, cod, and flatfish. In this way many bodies of water have been restocked after indiscriminate destruction.

Geographical Distribution of Fishes. A simple and seemingly natural classification of fishes, as regards their habitat, is a division into fresh-water and marine forms; and this will serve our purpose if it be remembered that there has been much interchange of species between the two media. In general, the truly fresh-water species of the world vary in connection with the great faunal regions mentioned on page 94. In the North American and Eurasian realms some important fresh-water families are the sunfishes (*Centrar'chidæ*), the perches (*Per'cidæ*), and the catfishes (*Silur'idæ*). Many of the salmon and trout are inhabitants of fresh water, though some of the larger species are marine, visiting fresh water only to lay their eggs. The peculiar distribution of the few lung-fishes which have survived the vicissitudes of geological time has already been mentioned. When allied species of animals are widely scattered over the globe in small separated areas, the distribution is spoken of as *discontinuous*.

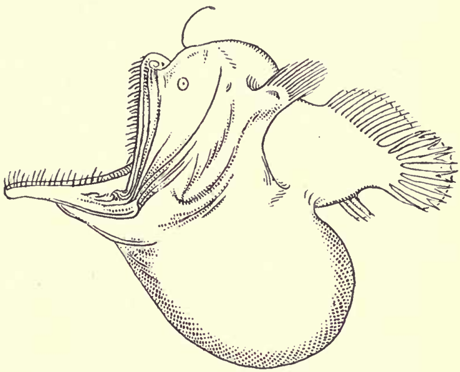


Fig. 161. Deep-Sea Fish
(From Günther's *Fishes*)

There are three common divisions of the ocean fauna, — the *littoral* or shore fauna, the *pelagic* or open-sea fauna, and the *abysmal* or deep-sea fauna. The shore fishes never venture far into the open sea. Among them are to be included the large members of the salmon family already referred to. The pelagic fishes are mostly hunters of other animals in the sea and are strong swimmers, as befits their environment. Typical fishes of this type are many of the sharks.

The most peculiar forms belong to the deep-sea fauna. There, of course, the conditions are unusual; life must be adapted to an enormous pressure, to a low temperature (not far above freezing), and to absolute darkness, except where it is lit up by some phosphorescent animal. Hence the fishes found in the deep waters are most bizarre, characterized by uniformity of color-pattern, often black, though brighter colors are sometimes developed; by modifications of the eyes, either very large in proportion to the size of the fish, or entirely absent; by the development of tactile and phosphorescent organs; and by hypertrophy (increase of size) of mouth, jaws, and stomach, which enables the fish to swallow an animal larger than itself. Fig. 161 shows one of these species.

Geological Development of Fishes. We left the geological history of the development of animal life on the earth at the

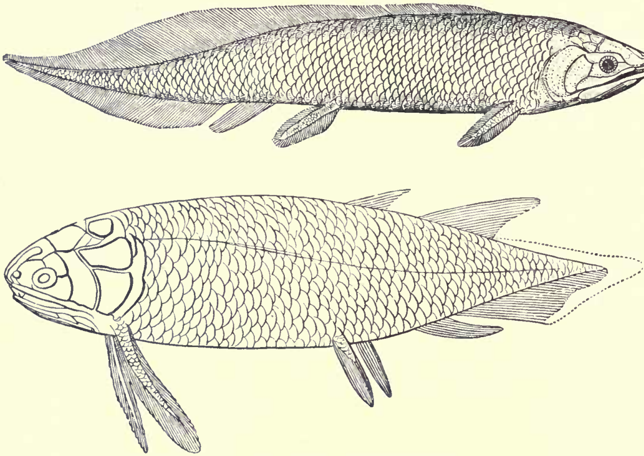


Fig. 162. Devonian Fishes

end of the Age of Invertebrates. A glance at the map on page 295 will serve to recall the appearance of our continent at that time. In North America the Age of Invertebrates passed slowly and quietly into the *Devonian Period*, or *Age of Fishes*. Though numerous kinds of invertebrates already in existence rose into prominence, or passed away to give place to new forms, the chief interest centers about the fishes. Geology gives us no hint concerning the remote ancestry of the class. The earliest fossil fishes, which belong to the latter part of the Age of Invertebrates, are representatives of the sharks and rays, lung-fishes, and, among the bony fishes, forms related to the garpikes of to-day. Thus all the great groups of fishes were in existence very early, with the single exception of the most specialized bony fishes, of which the perch is an example. Fig. 162 shows two species of Devonian fishes.

The earliest fossil remains of the sharks and rays are fragments of teeth and spines, for the skeleton was not fully ossified and no coat of mail was developed. The shark-like forms rose to great prominence in the course of the Age of Fishes, a little later becoming the predominant type of fishes, of which our species to-day are but the scattered remnants. The sharks are especially interesting in that they probably represent most nearly the ancestral condition of all fishes, and hence of all animals with a back-bone. The rays are more modern descendants of the group, adapted to life on the bottom.

The lung-fishes were also a dominant group very early in the period. By the end of the next succeeding age they had practically disappeared, leaving, as has been noted, but few descendants to-day. Some of them, which have been found in the rocks of Ohio, were giants among fishes; they were covered with great plates, at least anteriorly, and ranged in length from ten to twenty-five feet.

Among the gar-forms there are many well-preserved specimens, owing to the fact that these fishes were incased in a complete coat of mail formed of closely interlocking bony plates, such as those found in the garpike and, in vestigial form, in the sturgeon of to-day.

The other bony fishes, forming ninety-five per cent of all the species of fishes to-day, may well be called modern fishes, since they did not make their appearance till long afterwards, in the Age of Reptiles.

The question of the ancestry of the fishes is one of the most interesting problems of zoölogy. Though, as we have seen, geology fails to answer that question, and probably never will be able to answer it, on account of the presumably soft character of the ancestral type; still, by considering what has been learned from geology, in connection with the facts of embryology, it will be possible to trace the evolution of certain organs. Thus the scales, which form so characteristic a covering of most fishes to-day, can be traced to their origin in limy tubercles, like those forming the shagreen of sharks. Teeth originated from the same structures along the margin of the mouth. The fins are looked upon by some ichthyologists (students of fishes) as remnants of a once continuous fold of skin (Fig. 163); others regard these structures as having originated from external gills, or from modified gill-arches. Gills first arose as slits in the wall of the alimentary canal, and the air-bladder is a branch of the same structure.

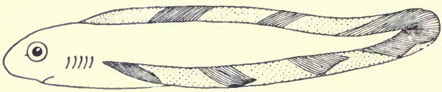


Fig. 163. Dermal Fold of Fish. (After Wiedersheim)

The land area of North America did not greatly change throughout the Age of Fishes, though a gradual increase in size is to be noted, preparing the way for a greater development of land animals and plants, to which reference will be made after some study of the frog and its allies in the following chapters.

CHAPTER XXV

THE GREEN FROG

Cardanus undertakes to give reason for the raining of *Frogs;* but if it were in my power, it should rain nothing but Water *Frogs*, for those, I think, are not venomous. — Izaak Walton, *The Complete Angler.*

Habitat and Distribution. The green frog (*Ra'na clam'itans*) is one of the commonest species of frogs in the eastern United States. It frequents the neighborhood of springs and meadow

Fig. 164. Photograph of Bullfrog. Reduced

brooks, and may be distinguished from its larger relative, the bullfrog (*Rana catesbia'na*, Fig. 164), by the presence of two glandular folds of skin along the sides of the back.

External Structure. The body is divisible into a *head* and *trunk;* there is no visible tail. The body-covering is a soft, smooth *skin* without scales, abundantly supplied with mucus-glands. There are four appendages, — the *limbs*, the anterior of which are divisible into *upper arm*, *forearm*, and *hand;* the posterior, into *thigh*, *lower leg*, and *foot*. The hand ends in four short *fingers;* the foot, in five *toes*, joined by a web. Both fingers and toes are often spoken of as *digits*. The *eyes* are situated prominently on the top of the head, and possess, in addition to an upper eyelid, a thin fold of skin called the *nictitating membrane*, which can be drawn across the eye-ball from below. There is no true lower eyelid. In front of the eyes, near the anterior end of the head, are the external openings of the *nostrils;* posterior to the eyes are smooth, round spots, the *tympanic membranes*, the outer portions of the frog's ears.

The Digestive System. The wide *mouth-cavity* (Fig. 165, 1) narrows into the short, straight *œsophagus* (Fig. 165, 6). Conical *teeth* are placed along the edge of the upper jaw (Fig. 165, 2) and on the roof of the mouth. A thick, fleshy *tongue* (Fig. 165, 3), notched posteriorly, is attached by its anterior margin to the ventral surface of the mouth-cavity. The tongue can be thrust out suddenly for quite a distance to capture food, which consists largely of insects, worms, and mollusks. Two openings lead from the mouth to the nostrils (Fig. 165, 4), and two openings (the Eustachian tubes, Fig. 165, 5) communicate with the ears. The *stomach* (Fig. 165, 7) is a thick-walled sac tapering gradually into the coiled *small intestine* (Fig. 165, 8). Beyond the small intestine the alimentary canal suddenly increases in diameter, forming the *large intestine* or *rectum* (Fig. 165, 9), which passes without change of diameter into the terminal *cloaca* (Fig. 165, 10), communicating with the surface at the *cloacal opening* (Fig. 165, 11). Between the lobes of the *liver* (Fig. 165, 13) lies a large *gall-bladder* (Fig. 165, 14). A *pancreas* (Fig. 165, 15) and a *spleen* (Fig. 165, 16) are present.

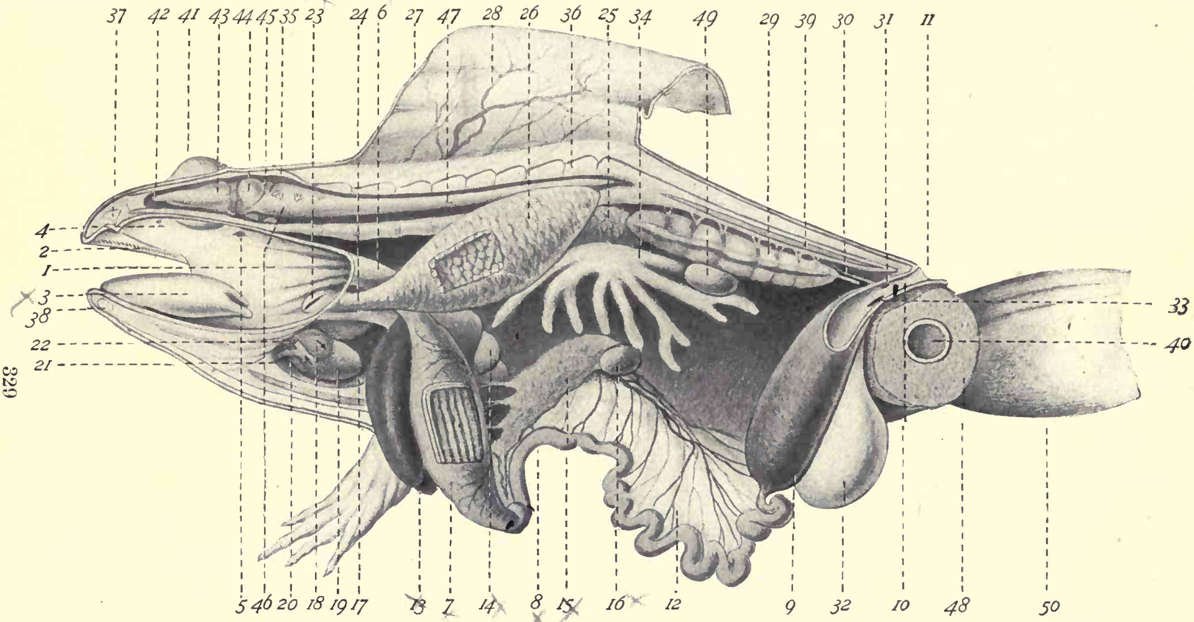


FIG. 165. Dissection of the Green Frog (*Rana clamitans*). Enlarged

1, mouth-cavity; 2, teeth on upper jaw; 3, tongue; 4, posterior nostrils; 5, opening of Eustachian tubes; 6, œsophagus; 7, stomach; 8, small intestine; 9, rectum; 10, cloaca; 11, cloacal opening; 12, mesentery; 13, liver; 14, gall-bladder; 15, pancreas; 16, spleen; 17, pericardium; 18, left auricle; 19, ventricle; 20, right auricle; 21, right branch of artery leaving the heart; 22, left branch of artery leaving the heart; 23, glottis; 24, trachea; 25, right lung; 26, left lung; 27, skin; 28, blood-vessels of skin; 29, kidney; 30, right ureter; 31, aperture of right ureter into cloaca; 32, urinary bladder; 33, aperture of bladder into cloaca; 34, fat-body; 35, cranium; 36, vertebra; 37, nasal bone; 38, cartilage in lower jaw; 39, urostyle; 40, socket of femur; 41, eye; 42, olfactory lobe; 43, cerebrum; 44, optic lobes; 45, cerebellum; 46, medulla; 47, spinal cord; 48, muscles of left leg; 49, spermary; 50, muscles of right leg

The Circulatory, Respiratory, and Excretory Systems. The *heart* inclosed in its sac, the *pericardium* (Fig. 165, 17), has one chamber more than the heart of the perch, by the division of the auricle into two parts, a *right* and *left auricle* (Fig. 165, 20, 18). The blood is aërated in the *lungs* (Fig. 165, 25, 26), the walls of which are traversed by the capillaries of the blood-system. The lungs communicate with the exterior by means of the windpipe or *trachea* (Fig. 165, 24), opening into the mouth by a narrow slit, the *glottis* (Fig. 165, 23).

Owing to the additional chamber in the heart and the presence of lungs, the course of circulation in the frog is somewhat different from that in the perch. The aërated blood returned from the lungs by the pulmonary veins is poured into the left auricle; the non-aërated blood from all over the body is returned to the right auricle. The auricles contract at the same instant, forcing both venous and arterial blood into the ventricle (Fig. 165, 19), which in turn contracts before there has been much mixing of the two kinds of blood, emptying its contents into the arterial circulation, the beginnings of which are shown in Fig. 165, 21 and 22. As the arterial system takes its rise from the right side of the ventricle, the first blood to enter the arteries is non-aërated. Owing to the less pressure in the arteries which supply the lungs and skin, and the presence of valves which cut the blood off from easily entering the arteries that supply the head and body, most of the non-aërated blood goes to the lungs and skin. The blood which follows is a mixture of aërated and non-aërated blood, and the pressure being raised by the presence of non-aërated blood in the capillaries of the lungs and skin, this blood forces the valves aside and makes its way to the different parts of the body, except the head. In the course of the artery leading to the head is a structure (the carotid gland) which temporarily obstructs the flow of blood till the body-arteries have become filled; and the supply of mixed blood having become exhausted, the head receives only aërated blood. The impure blood from the organs of the body-cavity and from the hind legs returns either through the liver or the kidneys; while that from the head, the fore limbs, and from the skin and muscles generally, is poured directly into the right auricle.

The frog breathes with the mouth closed. By depressing the tongue, air is drawn into the mouth-cavity through the nostrils. When the tongue is raised the nostrils close by valves and the air is forced into the lungs. Considerable exchange of gases takes place through the soft, moist skin, which is well supplied with blood-vessels (Fig. 165, 28).

The lymphatic system is well-developed in the frog, and the lymph is assisted in its circulation by two pairs of *lymph-hearts*, one at the posterior end of the body, and one in the region of the shoulders. The pulsations of the posterior lymph-hearts can be observed externally in the living frog.

The *kidneys* (Fig. 165, 29) are a pair of oval, dark-red bodies lying in the dorsal part of the body-cavity. The *ureters* (Fig. 165, 30) open from them into the cloaca (Fig. 165, 31). The *urinary bladder* (Fig. 165, 32) is a large, thin-walled sac projecting ventrally from the cloaca, and is a very different organ from the urinary bladder of the perch, which is a dilatation of the ureter. The function of the two organs is, however, the same, that of receiving the liquid nitrogenous waste from the kidneys.

The Skeletal System. In general, the skeleton of the frog is built upon the plan seen in the perch, but its appendages are considerably more specialized. The *skull* (Fig. 166, 1) is flattened and the *cranium* articulates with the first vertebra by two surfaces, or *condyles*. The *vertebral column* consists of nine vertebræ, terminated by a long bone called the *urostyle* (tail-bone) (Fig. 166, 3).

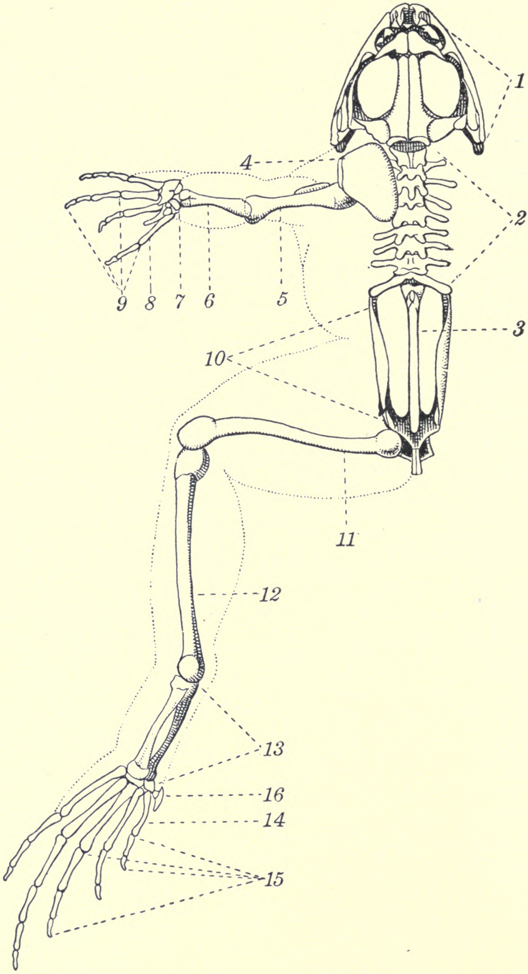


Fig. 166. Skeleton of Frog. Natural size. (After Duges)

1, skull; 2, vertebral column; 3, urostyle; 4, scapula; 5, humerus; 6, radius and ulna; 7, carpus; 8, metacarpals; 9, phalanges of fore leg; 10, pelvic girdle; 11, femur; 12, tibia and fibula; 13, tarsus; 14, metatarsals; 15, phalanges of hind leg; 16, rudimentary toe

The bones of the arms are attached to a *shoulder-girdle* consisting of the shoulder-blades or *scapulæ* (Fig. 166, 4), two *coracoids*, and two collar-bones or *clavicles*. A broad breast-bone (*sternum*) extends a short distance along the median ventral line. Each of the anterior limbs contains one bone in the upper arm, called the *humerus* (Fig. 166, 5); one bone in the forearm, composed of two bones united, — the *radius* and *ulna* (Fig. 166, 6); six bones in the wrist-region, or *carpus* (Fig. 166, 7); four complete sets of bones in the palm (*metacarpals*, Fig. 166, 8); and four complete sets of finger-bones (*phalanges*, Fig. 166, 9). The metacarpals and phalanges of the inner digit are rudimentary.

The leg-bones are attached to the vertebral column by means of a *hip* or *pelvic girdle* (Fig. 166, 10), of peculiar shape. The skeleton of each leg consists of one bone in the upper leg, the *femur* (Fig. 166, 11); one bone in the lower leg, formed from two bones united, the *tibia* and *fibula* (Fig. 166, 12); five bones in the ankle-region, or *tarsus* (Fig. 166, 13); and five complete sets of *phalanges* (Fig. 166, 15). A sixth rudimentary digit is also present (Fig. 166, 16), consisting of one metacarpal bone and two phalanges.

The Nervous and Muscular Systems. The nervous system is similar in general plan to that of the perch. The *brain* has large cerebral hemispheres (*cerebrum*, Fig. 165, 43), each of which is prolonged anteriorly into an *olfactory lobe* (Fig. 165, 42). The *optic lobes* (Fig. 165, 44) are also large, but the *cerebellum* (Fig. 165, 45) is small. Behind the cerebellum is the *medulla oblongata* (Fig. 165, 46), at the posterior end of which the *spinal cord* (Fig. 165, 47) arises. The *nerves* are not shown in the dissection. The *muscles* are arranged in bands or spindle-shaped masses instead of in segments, and the frog is capable of much more complex movements than the perch.

The Reproductive System. The *spermaries* of the male frog (Fig. 165, 49) are bean-shaped bodies lying beneath the kidneys, to which they are attached. The *ovaries* of the female frog when mature fill up a large portion of the body-cavity. Attached to the anterior end of the spermaries and ovaries are the *fat-bodies* (Fig. 165, 34), — lobed organs which attain their fullest development in the spring. These organs are believed to be of use as storehouses of reserve material, rendering possible the formation of large numbers of spermatozoa, or eggs, without complete exhaustion of the animal. After the spawning season the fat-bodies decrease in size.

Development. The eggs of frogs (Fig. 167, 1, 2, 3) are laid early in the spring in shallow water in large, jelly-like masses. They are fertilized by the male as they leave the body of the female. Within a week or ten days they hatch, the time required depending largely upon the temperature of the water. At first the young is blind, and is without gills or a mouth; it fastens itself to weeds and other objects in the water by means of a crescent-shaped, adhesive apparatus at the anterior end (Fig. 167, 4). Certain areas of the body are covered with cilia, by the vibration of which the animal is able, even without using its tail, to go forward in the water. Eyes, external gills, and a mouth provided with horny jaws soon appear, and the young, now the familiar tadpole, begins to feed on plant food (Fig. 167, 5). The alimentary canal is long and coiled, as it usually is in animals which feed upon plant material. The heart has two chambers.

As the tadpole increases in size (Fig. 167, 6) the first or primary gills are replaced by secondary gills, which soon become covered with a fold of skin, the *operculum.* The growth of the operculum continues till the gill-openings are covered, leaving a small hole usually on the left side. In this fish-like condition the tadpole continues through the summer, and on the approach of cold weather buries itself in the mud, where it hibernates. In some species of frogs the tadpole develops into the adult form in the course of a single season.

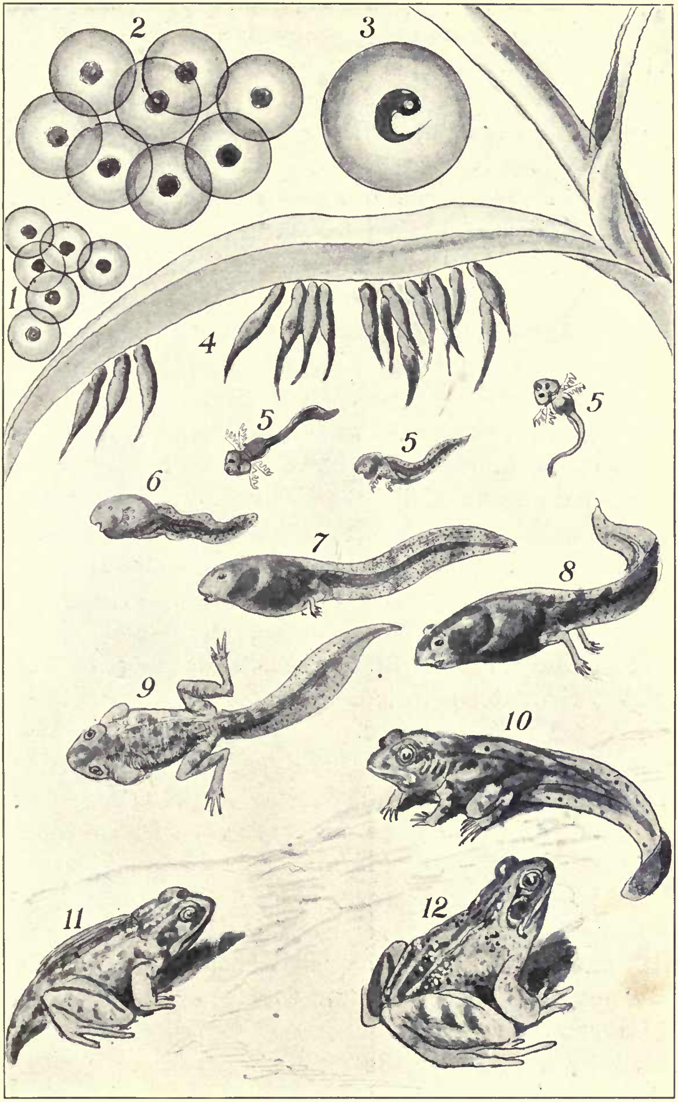


Fig. 167. Development of Frog

1, 2, 3, eggs; 4, young immediately after hatching; 5, tadpole with external gills; 6, 7, 8, 9, 10, and 11, further stages of development; 12, frog

(From Baskett's *Story of the Amphibians and Reptiles*)

If the adult condition has not been reached, the tadpole continues its growth the following summer. The hind legs appear (Fig. 167, 7, 8), and grow to be about an inch long, when the fore legs suddenly appear (Fig. 167, 9, 10). The front legs are really formed as early as the hind legs, but they are kept beneath the skin for a while. The broad and compressed tail, which forms the tadpole's chief organ of locomotion, is gradually absorbed, and the young frog finally hops out on land with only a stump of a tail remaining (Fig. 167, 11). By the time these changes have taken place externally, important changes have gone on inside: the gills have been replaced by lungs; one of the chambers of the heart has been divided; the intestine has become shorter, fitting the frog better for an animal-diet; and the horny jaws have given place to a wide mouth with teeth. This metamorphosis is retarded by cold, and accelerated by rest and freedom from disturbance of the water. The frog (Fig. 167, 12) grows for several years without further metamorphosis, except the gradual disappearance of the stump of the tail. Throughout life the outer skin is cast periodically in a single piece and immediately devoured.

Relation to Environment. The dark-green and brown colors of the upper surface afford considerable protection among the water-plants and along the muddy or grassy margins of ponds and streams, and the white under surface may be similarly useful in the water.

The green frog is a voracious feeder, and varies its diet with almost every kind of small creature which comes its way, not hesitating in the least to devour smaller individuals of its own kind. Usually only moving objects are seized, and it has been said that the frog may starve to death in the midst of an abundance of food if there is no movement to attract its attention. The eyes are situated high on the top of the head, where they maintain a wide survey. Every boy in the country knows of the difficulty of approaching these alert creatures, and he knows, too, how to capture them by dangling a hook with a piece of red flannel in front of them. Even if well fed the frog seems to find the moving object irresistible, and seizes it with wide-open mouth. The tongue is covered with a sticky substance, and can be swiftly extended with unerring aim to a distance of several inches.

While the frog depends very largely on the sense of sight to warn it of approaching enemies or enable it to distinguish food, the sense of hearing is also of considerable value. Dr. R. M. Yerkes, of Harvard University, who has studied the sense of hearing in frogs both in the laboratory and in the field, says that he is convinced that sounds which are of importance in the life of the animal, as the splash made by a frog jumping into the water, are not only heard, but that such sounds serve to put other frogs on their guard. The croaking of male frogs in the spring is undoubtedly heard by the female, and serves to make mating more certain.

The observer just quoted does not give the green frog credit for much intelligence, as his experiments seem to show that nearly all the frog's actions are repeated with machine-like accuracy, and new habits are learned very slowly. He is inclined to think that even the perch learns more rapidly than the frog. He also notes that the frog is very timid, and that fright tends to lengthen the process of learning.

When suddenly touched, the frog may do one of several things: it may jump, using the strong hind legs sometimes with force enough to carry it several feet; it may remain perfectly quiet; or it may crouch with its head close to the ground, at the same time puffing itself out. This last action, Dr. Yerkes has noticed, more often takes place when the animal is touched in front, and is probably useful to render seizure difficult, or to prevent it altogether. If the frog leaps away, it is usually into the water with a loud "plunk." A few swift strokes of the hind legs serve to carry the animal to shelter beneath protecting débris in the water. There it is able to remain for a considerable period without the necessity of rising to the surface for oxygen, owing to the low state of all the life-processes. The frog has numerous enemies, among which are owls, hawks, and herons, many snakes and other reptiles, and several fur-bearing creatures which come to the water in search of food.

During the winter green frogs, like some other frogs, hibernate in the mud at the bottom of pools. With returning spring they congregate to lay their eggs, and the males may then be heard calling to the females in an unmusical "chung," "chung," which is not as familiar a sound, perhaps, as the bass voice of the bullfrog or the high-pitched, insistent note of the spring "peepers" (p. 344). After providing for the reproduction of the species, the green frog spends the rest of the summer in its rather solitary life on the bank of some stream or spring-hole.

CHAPTER XXVI

THE ALLIES OF THE FROG: AMPHIBIA

Blue dusk, that brings the dewy hours,
  Brings thee, of graceless form in sooth
Dark stumbler at the roots of flowers,
  Flaccid, inert, uncouth.

EDGAR FAWCETT, *A Toad.*

Definition of Amphibia (Gr. *amphibios*, capable of living in both air and water). The frog belongs to the class *Amphib'ia*, to which belong also the toads, newts, and salamanders. Amphibians are cold-blooded vertebrates covered with a smooth or rough, moist skin, in which are numerous mucus-glands. In the immature state amphibians are adapted to a life in the water, and breathe by gills; when adult the gills are in the majority of cases absorbed, and the animals breathe by lungs. Four limbs are usually present. Nearly all amphibians are oviparous.

Two out of the three orders into which the class is divided will be discussed here. One of these orders includes the salamanders and newts, the other the toads and frogs.

Salamanders and Newts. The *Urode'la* (Gr. *oura*, tail; *delos*, conspicuous) are elongate forms, with rounded or compressed tail. They are often, but erroneously, called lizards, and resemble the latter only in external form. The eggs are laid usually in the water in strings, or in large masses resembling frogs' eggs, or singly, attached to the leaves of water-plants. Salamanders and newts hatch as tadpoles, which develop into the adult form without a strongly marked metamorphosis. The young of our common eastern species may be distinguished from the tadpoles of the toad, and from those of our various species of frogs, by their more elongate form, and by the presence, usually, of two short, rod-like organs, called "balancers," which project from the anterior end of the body near the mouth. The balancers may serve as sense-organs of touch, or as adhesive disks, in addition to the use suggested by their name. The gills are usually visible externally for a longer period than is the case with the toad and the frogs. Some species retain their gills throughout life, though the lungs are also functional; in others, though the gills are absorbed in adult life, the gill-openings are retained; in still others all traces of gills and gill-slits disappear; and, finally, a few species lose their lungs also, when mature, depending entirely upon the skin for respiration.

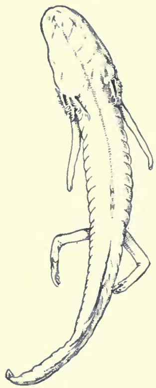


Fig. 168. Cave Salamander. Slightly Reduced. (After Eigenmann)

Of the five species which retain their gills throughout life, three are found in the surface-waters of the eastern and southeastern United States, and one in the subterranean waters of Austria and Texas respectively. Both the cave-inhabiting species live in absolute darkness, far below the surface of the earth, and are colorless and blind. The white skin is sensitive to light, and has been changed to a black color after several months of exposure under ordinary conditions. Fig. 168 shows the Texan cave salamander (*Typhlomol'ge rath'buni*) from an artesian well one hundred and eighty-one feet below the surface.

The genus *Amblys'toma* includes some of the largest of our species, known by the common name of blunt-nosed salamanders. The color is black, spotted with yellow. As these salamanders are protected by an acrid secretion from the mucus-glands of the skin, the conspicuous colors are possibly to be interpreted as warning coloration. The adults live in damp places and lay eggs in the water in large masses resembling frogs' eggs, though the jelly-like mass which surrounds them is more opaque. The young keep their gills for a considerable period, and one species, called the axolotl (*Amblystoma tigri'num*, Fig. 169), found from New York to California and Mexico, may even breed in the gill-bearing larval stage. These immature forms live in the water, growing to be eight or nine inches long, or, in exceptional cases, even larger, and may continue in this condition for years, without ever changing to the adult form. An observer who has

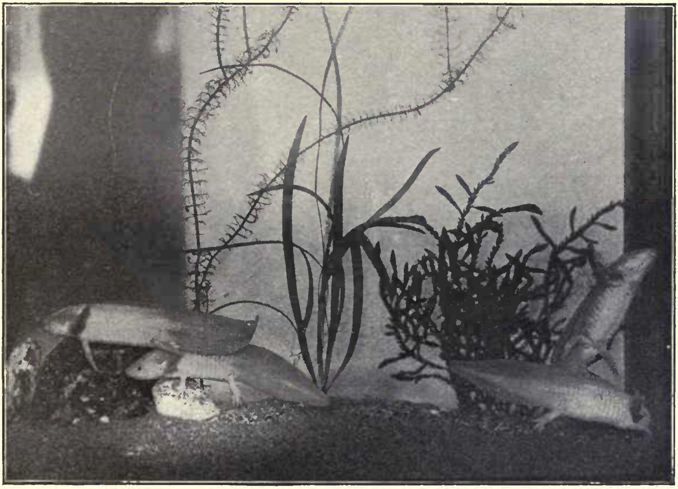


FIG. 169. Photograph of Young Axolotl. Reduced. (By H. V. Letkemann)

had opportunity to study axolotls in their native habitat says that the change to the adult condition is hastened by abundance of food, and by the partial drying up of the water and consequent increase in temperature of the water which remains.

Like some other amphibians these salamanders can regenerate lost limbs. This, according to Professor Gadow, of Cambridge, England, takes place more certainly and quickly the younger the animal is. In one case quoted by this authority the hand of an axolotl ten years old was removed, and it was replaced within twelve weeks. Often more than the usual number of digits is replaced; this tendency is greatest in those cases where the limb is cut off close to the body.

The Alpine salamander (*Salaman'dra a'tra*), found in moist places two thousand feet in altitude, especially near waterfalls, in the Alps of Europe, is remarkable for its breeding-habits. Only two young are produced at a time, and these are born alive at an advanced stage of development. During

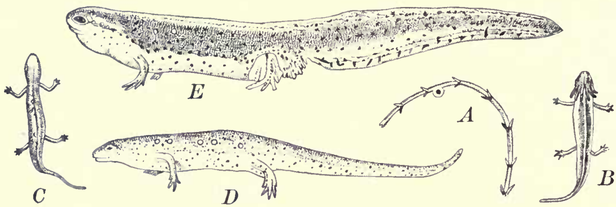


Fig. 170. Development of Newt. Reduced. (After Gage)

A, Egg on water-plant; *B*, larva (in August); *C*, young, in autumn; *D*, about two years old; *E*, adult

the time they are within the mother's body they are nourished by the nutritive matter from several eggs, which only partially develop.

The newts, or tritons, are carnivorous salamanders which are more or less aquatic in their habits when adult, or, at least, during the breeding-season, at which time also the colors of the males in some species become brighter, and a crest is developed along the back. The common species of the eastern United States (*Diemyc'tylus virides'cens*, Fig. 170) is olive-green or reddish in color, with a compressed tail and a row of small orange-colored spots along the right and left sides of the body. It grows to the length of three and a half inches. The eggs (Fig. 170, *A*) are laid during April, May, or June, usually in the axils of leaves of water-plants, and the leaves are drawn together and made into a compact mass by a secretion from the oviduct. As a general rule one egg is laid at a time; occasionally two are inclosed in the same mass. The young hatch in from twenty to thirty-five days, depending on the temperature. In August they resemble Fig. 170, *B*. Late in the fall they leave the water and live on land in damp places beneath logs and leaves in the woods. They are then of a beautiful red color and have a cylindrical tail (Fig. 170, *C*). Several years are required to produce the aquatic adult form (Fig. 170, *E*).

Toads and Frogs. The members of the order *Anu'ra* (Gr. *an*, without; *oura*, tail) undergo a well-marked metamorphosis. They are tadpoles at first, and later change to the adult condition by the absorption of the tail and the development of legs.

Many examples of peculiar breeding-habits are known. The female of a Brazilian species of tree-frog (*Hy'la fa'ber*) lays her eggs within a circular wall of mud which she constructs on the bottom of a shallow pool of water. Within this nursery the tadpoles develop, unless liberated by the rain or other accident. Several species lay their eggs on the leaves of trees above the water, into which the young fall when hatched. The male of the obstetrical toad of Europe (*Al'ytes obstet'ricus*) winds the eggs around his legs, and, seeking a safe place, guards them till they hatch. In a South American species, the famous Surinam toad (*Pi'pa americа'na*), the eggs are spread by the male over the back of the female, where each egg becomes covered with a growth of skin, forming a pouch with a lid. Here development goes on, and the entire metamorphosis takes place within the egg. In a Chilian species (*Rhinoder'ma Darwin'ii*) the eggs are transferred by the male to vocal sacs at the side of the mouth, which become greatly developed at the breeding-season. Metamorphosis takes place within these sacs, and the young escape in the adult condition. In half a dozen species of tree-frogs from South America (*Nototre'ma*) the females possess dorsal pouches in which the eggs are placed. The young appear either as tadpoles or as perfect frogs.

The tree-frogs or tree-toads are forms adapted to an arboreal existence. They possess soft pads on the end of the digits. Many of them, like our common tree-toad (*Hyla versic'olor*, Fig. 171), are protectively colored, and have the power of changing their color through various shades of gray and green. A South American species is conspicuously marked with red and blue. Experiments seem to show that it is so well protected by an acrid secretion that it is not fed upon by birds, which might otherwise devour it. Several of our smaller species of tree-toads, called "peepers" in the country, give utterance to shrill notes, which are among the first sounds of spring. In that season they seek the ponds to mate and lay their eggs.

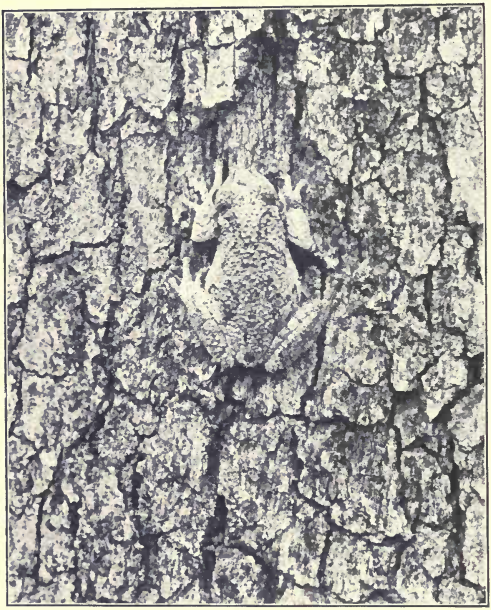


Fig. 171. Photograph of Tree-Frog. Reduced

The common toad (*Bu'fo lentigino'sus*) is one of the farmers' most valuable allies in the destruction of injurious insects. Despite the prejudice which its appearance still excites among those who do not understand it, the animal is a most interesting object for study. There is no truth in the oft-repeated statements of its poisonous qualities, except in so far as the acrid secretion of the skin, which is a protection to many amphibians, might be injurious if it gets on sensitive surfaces, such as the lining of the eyelids. The dark-colored eggs are laid in long strings, like a string of beads, in shallow water, usually in April, in the latitude of New York. They hatch in two or three weeks into small black tadpoles, which pass through their transformation within about two months.

Geological Development of Amphibians. As time passed on from the Age of Fishes a large portion of the great interior sea of North America, shown on the map, page 295, became a region of swamps, though many times depressed and exposed to the inroads of the sea. These conditions brought about the formation of the great coal-beds of the continent, alternating with beds of shale, sandstone, and clay. When the land was above the surface of the water, vegetation flourished in more than tropical luxuriance; when the land was depressed, the ocean-waters rolled in and destroyed the life of the land. The swamps of that time are the coal-beds of to-day, and the period is known as the *Carboniferous Age* or *Age of Coal Plants.* Though fishes and many invertebrate forms were abundant, progress had been made over preceding periods in the development of back-boned creatures adapted to breathing air. These were amphibians, and from the prevalence of species of this order the period is often called the *Age of Amphibians.* There were snake-like forms without limbs, and forms with every degree of limb-development.

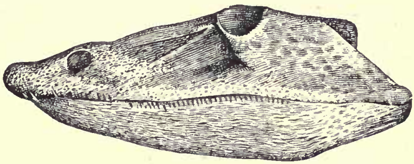


FIG. 172. Skull of Labyrinthodont

Some species grew to be as large as alligators. Their skulls (Fig. 172) were solidly roofed over with bone. Their teeth, in many cases, showed complicated foldings of the enamel; hence they have been called labyrinthodonts, i.e. labyrinth-toothed (Fig. 173). There is little doubt that the labyrinthodonts descended from the fishes. Anurans and urodeles did not appear till later. Both are probably descended from the labyrinthodonts, each by its own line of ancestry.

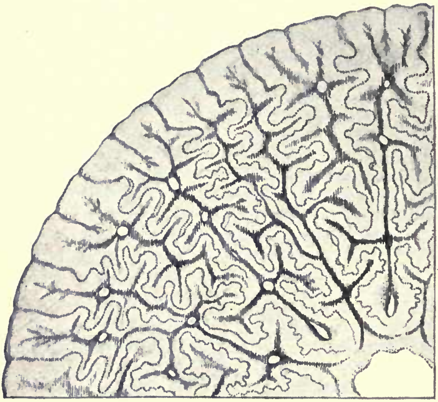


FIG. 173. Section of Tooth of Labyrinthodont (From Baskett's *Story of the Amphibians and Reptiles*)

The close of the Age of Amphibians is marked by a great change in the topography of North America, for it was at this time that the Appalachian system of mountain ranges was uplifted. This brought a great area of land in eastern North America above the level of the sea, as is shown on the map (Fig. 174). No species of animal of earlier time is known to have existed after this upheaval. The causes underlying the culmination and decline of so many species at this time are not thoroughly understood. They are probably connected with the changes already spoken of, with the decline in the temperature, and with the slow removal of carbon dioxide from the atmosphere.

Paleozoic Time: Era of the Ancient Forms of Life. The geological periods so far considered since the close of Archæan Time (see pp. 295, 324, and 345) are usually grouped under the general heading of *Paleozoic Time*, or the *Era of the Ancient Forms of Life*. The paleozoic invertebrate world was peculiar in its corals, crinoids (p. 246), trilobites (p. 153), brachiopods (p. 233), mollusks of the orthoceras-type (p. 193), and in its insects, which were largely of those groups which develop without metamorphosis. Among the vertebrates, the fishes represented were sharks and rays, gar-forms and

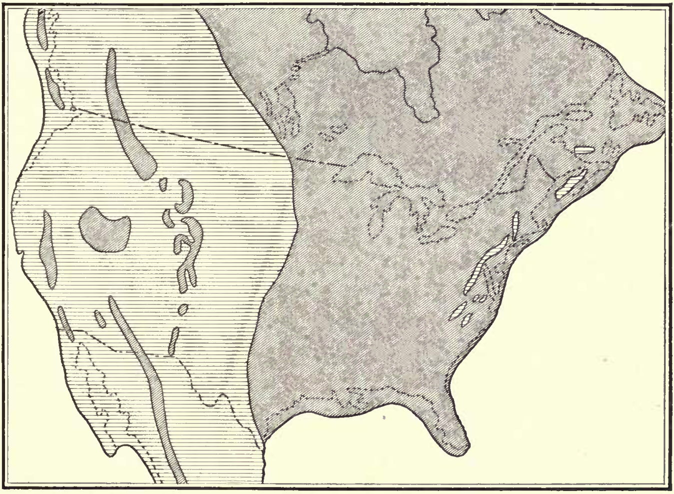


Fig. 174. North America after the Appalachian Revolution
(From Dana's *Manual of Geology*)

lung-fishes. The Appalachian revolution wiped the trilobites entirely out of existence; the corals and orthoceras-forms disappeared soon after, with but few exceptions; the brachiopods were much diminished in numbers; and the insects which developed without strongly marked metamorphosis after hatching dwindled away before the rapid rise of forms which underwent a complete metamorphosis. The sharks, rays, gars, and lung-fishes of the era became extinct as the higher bony fishes began to people the sea.

CHAPTER XXVII

THE PINE-LIZARD AND ITS ALLIES: REPTILIA

I only know thee humble, bold,
Haughty, with miseries untold,
And the old curse that left thee cold,
And drove thee ever to the sun
On blistering rocks.

Bret Harte, *The Rattlesnake.*

The Pine-Lizard

Habitat and Distribution. The pine-lizard (*Scelop'orus undula'tus*, Fig. 175), or swift as it is often called, is found in the eastern United States as far north as Michigan, preferring the more sandy areas covered with pine. It is a graceful little creature about seven inches long, gray in color above, with faint undulating black stripes, and silvery white below. The male is ornamented with lustrous patches of blue or green, edged with black on the sides of the throat and under surface of the body. Old fences which border pine-lands are favorite resorts, and here it pursues and captures countless insects. Like others of its kind this lizard loves the sun, and is to be found active only in the hottest part of the day. During the cold weather it hibernates, at least in the northern part of its range.

External Structure. The body is elongate in form, resembling that of the salamanders, but the skin is covered with scales instead of being smooth, and there are no mucus-glands. The digits of the four legs are long and slender, and have sharp claws, which are admirably fitted for clinging to inequalities in the bark of trees. The gray color of the back is protective when the lizard is at rest, and its movements are so quick that it is difficult for the eye to follow them. When alarmed the scales can be raised, the throat patches swollen, and the head elevated. The harmless little creature then looks quite formidable. In order to provide for growth the scaly skin is cast periodically.

Internal Structure. The internal structure is, in general, similar to that of the amphibians, but in several respects it

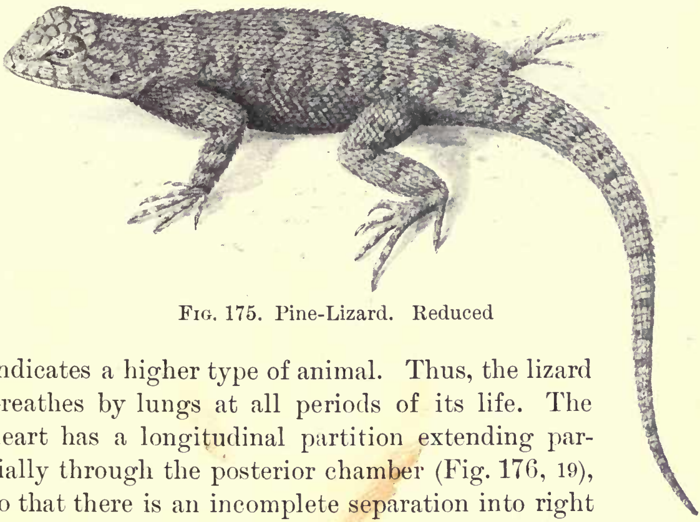


FIG. 175. Pine-Lizard. Reduced

indicates a higher type of animal. Thus, the lizard breathes by lungs at all periods of its life. The heart has a longitudinal partition extending partially through the posterior chamber (Fig. 176, 19), so that there is an incomplete separation into right and left ventricles. As in the frog, the left auricle (Fig. 176, 18) receives aërated blood returned from the lungs (Fig. 176, 30) by the pulmonary veins (Fig. 176, 24) and the right auricle receives the blood from the rest of the body (Fig. 176, 25). From the right side of the ventricle arises the pulmonary artery (Fig. 176, 23); from the left side are given off the branches of the artery supplying the head and body generally (Fig. 176, 20, 21, 22). When both auricles contract, the venous blood in the right auricle tends to keep to that side of the heart, and, by the aid of the incomplete partition, is forced into the pulmonary artery; the arterial blood from the left

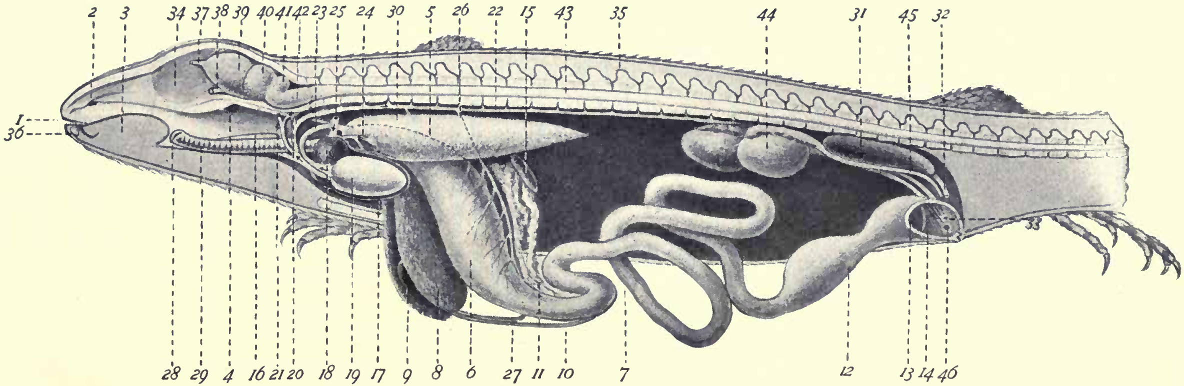


FIG. 176. Dissection of the Pine-Lizard (*Sceloporus undulatus*). Enlarged

1, teeth; 2, posterior nostril; 3, tongue; 4, opening of Eustachian tube; 5, line showing edge of stomach, at this point concealed by the lung; 6, stomach; 7, small intestine; 8, liver; 9, gall-bladder; 10, bile-duct; 11, pancreas; 12, rectum; 13, anterior division of cloaca; 14, posterior division of cloaca; 15, spleen; 16, thymus gland; 17, pericardium; 18, left auricle of heart; 19, ventricle of heart; 20, branches of artery leading from heart to head and arms; 21, branches of artery leading from heart to head and arms; 22, dorsal aorta; 23, pulmonary artery; 24, pulmonary vein; 25, vein leading to right auricle; 26, artery supplying stomach; 27, vein leading from alimentary canal to liver; 28, glottis; 29, trachea; 30, left lung; 31, kidney; 32, left ureter; 33, aperture of right ureter into cloaca; 34, cranial cavity; 35, vertebra; 36, cartilage in lower jaw; 37, olfactory lobe; 38, optic nerve; 39, cerebrum; 40, optic lobes; 41, cerebellum; 42, medulla; 43, spinal cord; 44, left spermary (right spermary just anterior); 45, left sperm-duct; 46, opening of sperm-duct into cloaca auricle, with some admixture of venous blood, is driven to the arterial branches supplying the head and body generally. The nervous system, especially the brain, is also more highly differentiated than in the amphibians, and the bones are more completely ossified. A skeletal difference is the articulation of the cranium to the first vertebra by means of a single condyle. A study of Fig. 176 will make clear the relation of the most important organs.

Development. The female pine-lizard lays her eggs in the ground, a short distance below the surface; ten or fifteen eggs are deposited in each lot. The eggs are oblong in shape, from fourteen to eighteen millimeters (a little over half an inch) in length, and are roughened on the surface, causing dirt to adhere to them. One lot brought to an observer in North Carolina late in the month of June had been plowed up. The eggs increased in size as the embryo developed, finally hatching in about two months. The young resemble the adult quite closely in everything but size. They are able to take care of themselves from the first.

The Allies of the Pine-Lizard: Reptilia

Definition of Reptilia. The pine-lizard will serve as an example of the class *Reptil'ia* (Lat. *repere*, to creep), which includes also snakes, turtles, tortoises, alligators, and crocodiles. Reptiles are cold-blooded vertebrates covered with scales or plates; they breathe by lungs throughout their life. A few reptiles are viviparous, but most of them lay eggs, from which the young hatch in the form of the adult.

Four out of the five groups into which the class may be divided, are here considered.

Lizards. Most of the *Lacertil'ia* (Lat. *lacerta*, a lizard) are, like the pine-lizard, elongate reptiles with four limbs and movable eyelids. A few families have, however, lost one or both pairs of limbs in connection with their adoption of a burrowing life, and the eyes have disappeared beneath the

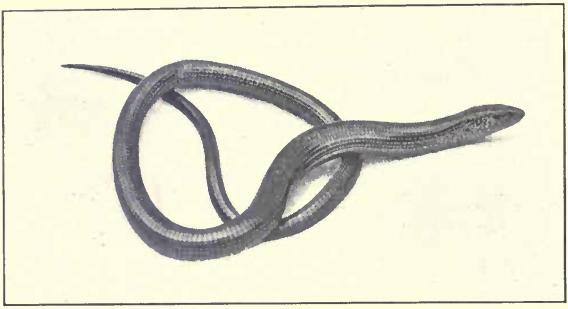


Fig. 177. Photograph of Legless Lizard

skin. The covering of scales, so characteristic of reptiles, has also in some cases become much reduced. Legless lizards

Fig. 178. Photograph of Mexican Iguana

(Fig. 177) may be distinguished from the snakes, which they resemble, by the fact that they are incapable of opening the mouth to so great an extent as snakes are.

Many lizards possess the power, when seized suddenly, of snapping off the tail, which may be left in possession of the captor, while the creature hurries away to safety. Fig. 179 shows a Mexican species of iguana which had thus responded to the efforts of the photographer to take its picture. The same animal before mutilation is shown in Fig. 178. The tail is usually reproduced, at least so far as the flesh and skin are

Fig. 179. Photograph of Mexican Iguana with Broken Tail

concerned; new vertebræ are not developed. The pattern of the scales on the newer portion is usually simpler, sometimes apparently reverting to an ancestral type.

The chameleons (*Chame'leo*) of the Old World are famous for their color changes, but the power is possessed to a greater or less extent by nearly all lizards. It is accomplished by the shifting of pigment granules in cells in the deeper layers of the skin, toward or away from the colorless outer skin. The movement of the granules, though affected by external conditions, such as color and temperature of surrounding objects, is said to be largely under the control of the animal.

Snakes. The snakes, which belong to the class *Ophid'ia* (Gr. *ophis*, a serpent), are usually very easily distinguished externally by the absence of eyelids and limbs, although rudimentary hind legs are to be found in a few forms, such as the pythons of Asia, Africa, and Australia. Teeth are present in all ophidians, and are of two types, — the ordinary teeth, used for seizing food, and the poison-fangs, which are perforated, forming a passage for the poison secreted in a gland at their base. Both kinds of teeth are shown in the illustration of the skull of the rattlesnake (Fig. 180), which shows also the gland where the poison is secreted (Fig. 180, 9), and the reserve fangs (Fig. 180, 11) which replace the first pair when the former are broken or shed. In the non-poisonous species the number of teeth is much greater than in the rattlesnake.

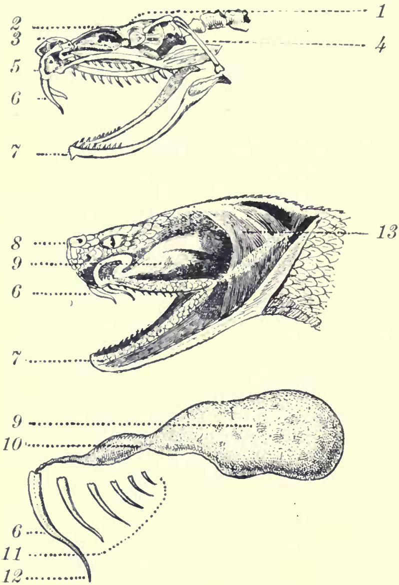


Fig. 180. Skull of Rattlesnake, showing Poison-Fangs

1, 2, bones of cranium; 3, prefrontal bone; 4, quadrate bone; 5, maxillary bone; 6, fang; 7, bones of lower jaw; 8, tip of snout; 9, poison-gland; 10, poison-duct; 11, reserve fangs; 12, tip of fang; 13, temporal muscle

(From Baskett's *Story of the Amphibians and Reptiles*)

The tongue of a snake is a long, slender, forked structure, used principally as an organ of touch. The lower jaw is joined to the upper jaw in such a way (see Fig. 180) as to admit of so much freedom of movement that the snake's mouth can be opened wide enough to swallow animals greater in diameter than itself. The passage of food into the œsophagus is facilitated by an abundant secretion from salivary glands, and escape of the prey is prevented by the sharp, backward-pointing teeth in both jaws. The union of the two sides of the lower jaw in front is so loosely made by a cartilaginous connection that each side of the jaw can be pushed forward independently, thus getting a fresh hold on the food-mass. Some of the larger snakes, as the pythons and boas, kill their prey by constriction; the non-poisonous kinds may swallow theirs alive; the poisonous species generally kill the animal, unless it be a small one. Snakes progress by means of muscles attached to the ribs and scales of the under side. These scales have a free posterior edge, which can be inserted into rough places in the surface of the ground.

The poisonous snakes of the United States are the prettily colored beadsnake (*E'laps ful'vius*) and the water-moccasin (*Agkis'trodon pisciv'orus*) of the southern states; the copperhead (*Agkistrodon contor'trix*), found from New England to Wisconsin and southward; and more than a dozen species of rattlesnakes (Fig. 181), found mostly in the arid regions of the West and Southwest. The use of the peculiar horny appendage at the end of the tail of the rattlesnake has occasioned much discussion. By some it has been thought to be a means of terrifying its prey, so that escape may be rendered

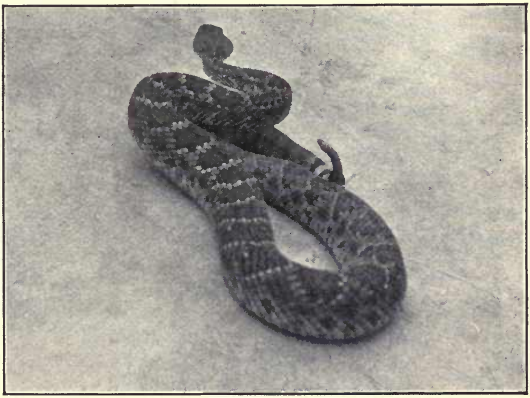


Fig. 181. Photograph of Rattlesnake

impossible; by others it has been regarded as a sex-call for its mate, or even as a lure for birds. Many naturalists consider that its function is similar to that of the yellow and black coloration of wasps, or the distinctive red markings of poisonous spiders, — features which serve to mark the possessor as having unusual means of defense. By the mere

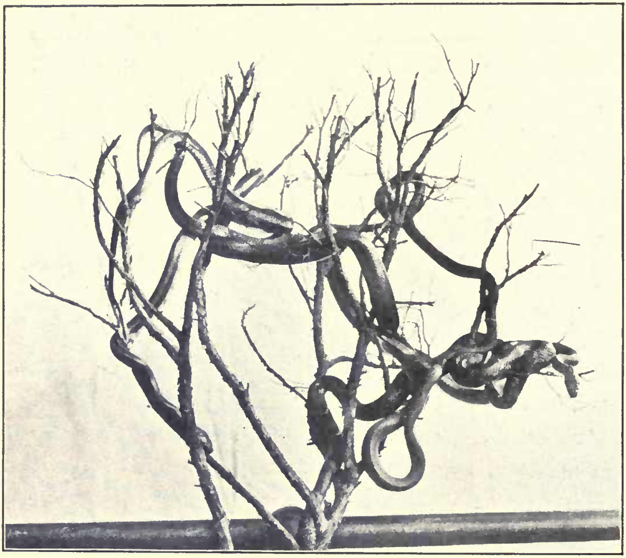


FIG. 182. Photograph of Blacksnakes

fact of this advertisement it is thought many conflicts are avoided which might prove disastrous to the rattlesnake, even if the attacker were killed in the contest. As it is, an animal must have some confidence in its powers, if it disregards the warning rattle and tries conclusions with the owner. A diamond-back rattlesnake in captivity in the New York Zoölogical Park grew a new "button" to the rattle every three months, on each occasion of shedding its skin.

Of the non-poisonous snakes of this country the little green snake (*Cy'clophis verna'lis*) is one of the most interesting and beautiful. When kept in confinement it is a harmless and interesting pet. As much cannot be said for our water-snakes (*Tropidono'tus*), which are of irritable disposition and disposed to strike when handled. Blacksnakes (*Basca'nion*, Fig. 182) have been kept in captivity and handled freely after they have become accustomed to their new surroundings.

Turtles and Tortoises. The turtles and tortoises, *Chelo'nia* (Gr. *chelone*, a tortoise), are externally the best protected of all the reptiles, being incased in a shell formed of plates firmly fixed to the vertebræ and ribs. Chelonians have no teeth, but the rim of the jaws is covered with a horny skin. The limbs are sometimes modified into flippers for locomotion in the water; to such species the name "turtle" is commonly applied. The tortoises are land and fresh-water species, with claws on the digits.

Of the turtles, the green turtle (*Chelo'ne my'das*) of the warmer portion of the Atlantic, Indian, and Pacific oceans, and the hawkbill (*Chelone imbrica'ta*), also widely distributed in warm ocean-waters, are economically important,—the first as an article of food, the second as the source of tortoise-shell. These turtles lay their eggs in immense numbers on sandy beaches in holes dug for the purpose by the female. As many as two hundred eggs may be laid by a single female. Within about six weeks they hatch, having been incubated by the heat of the sun. These turtles are captured by the natives of different parts of the world, by diving or by nets or harpoons. A peculiar method of capturing them is followed by natives of such widely separated regions as Torres Strait, Madagascar, and Cuba. This method consists in utilizing the services of the sucking-fish (*Echene'is*), a commensal fish provided with a sucker-like attachment on the top of the head, by means of which it is borne from place to place by larger fishes, especially sharks and swordfishes, leaving its host occasionally to procure food. A string is attached to one of these sucking-fishes, which is then liberated in the vicinity of turtles, where it soon attaches itself to the under

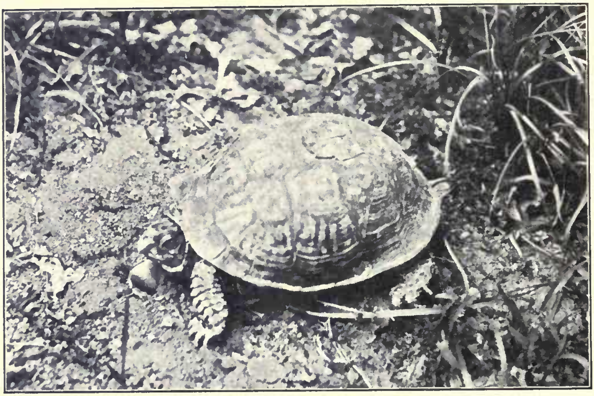


Fig. 183. Photograph of Box-Tortoise

surface of the shell, holding on so tenaciously that the turtle can be drawn gently to the surface. The method was noticed by Columbus or one of his companions, and was described in 1671, in Ogilby's *America*, as follows: "Somewhat further he [Columbus] saw very strange Fishes, especially of the *Guaican*, not unlike an Eel, but with an extraordinary great Head, over which hangs a skin like a bag. This Fish is the Natives Fisher, for having a Line or handsom Cord fastned about him, so soon as a Turtel, or any other of his Prey, comes above Water, they give him Line; whereupon the *Guaican*, like an Arrow out of a Bowe, shoots toward the other Fish, and then gathering the Mouth of the Bag on his Head like a Purse-net, holds them so fast that he lets not loose till hal'd up out of the Water."

A common species of tortoise in the eastern United States is the box-tortoise (*Cistu'do*, Fig. 183). These tortoises have a very convex upper shell; the lower portion is provided with a transverse hinge, which makes it possible for the animal to bring the two parts of the shell closely together, thus forming a box, within which are concealed head, neck, legs, and tail. A remarkable sex-dimorphism occurs; the eyes of the male are red, those of the female, brown. More flattened species, like the painted tortoise (*Chrys'emys*) and the spotted tortoise (*Nan'emys*), are better adapted to an aquatic existence.

Alligators and Crocodiles. The large reptiles known as alligators and crocodiles belong to the *Crocodil'ia* (Lat. *crocodilus*, crocodile). The heart in the crocodilians is highly specialized, having four separate chambers by the complete separation of the two ventricles. Alligators (Fig. 184) differ from crocodiles in having the canine teeth of the lower jaw fitting into pits in the upper jaw; in the crocodiles they fit into notches in the side of the jaw. A species of each kind is found in

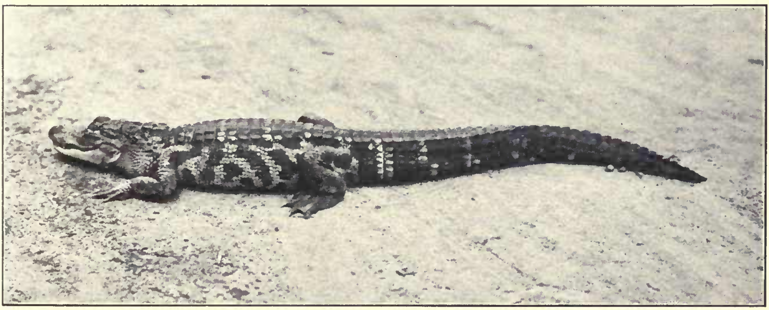


FIG. 184. Photograph of Alligator

Florida, though both have been sought so eagerly for the teeth and skin that they are now found only in the more inaccessible places. Crocodilians are also found in China, Africa, southern Asia, and South America. They frequent the edge of rivers, ponds, and lakes, lying in wait for their prey with only the tip of the snout exposed, or concealed in the vegetation at the edge of the water. They feed at night, and during the day bask in the sun on sand-banks or on logs.

Geological Development of Reptiles. We have seen (p. 345) that during the Age of Amphibians a great part of the interior of North America was one vast swamp, in which stretches of black water alternated with drier areas covered with the characteristic vegetation of the period, the whole bathed in the heat of a tropical climate. Under conditions similar to these the reptiles first came into existence in the latter part of the Carboniferous Age. They developed in numbers, size, and form, and became in the succeeding period so characteristic a part of the world's fauna that the age is named, from them, the *Age of Reptiles*. This forms the third great division of geological time, called *Mesozoic Time*, or the

Fig. 185. Ceratosaurus

Era of the Mediæval Forms of Life. In North America the era began with the upheaval of the Appalachian system of mountain ranges, as stated on page 347. During a part of the era great areas in the south and west were submerged beneath the ocean.

Fossil remains of the latter part of the Carboniferous Age link the reptiles with the amphibians, so that it is likely that the former are descended from a labyrinthodont ancestry. Some of the reptiles possessed certain skeletal characteristics

FIG. 186. Photograph of Model of Triceratops
(American Museum of Natural History)

of the fur-bearing animals, and they are called theromorphs (beast-formed) on that account.

On land many species of dinosaurs (terrible lizard) were found; some of them were the largest animals ever developed on the earth, reaching, in one case, the possible length of sixty or seventy feet and the height of nearly twenty feet. This animal was so great in bulk that it is considered hardly possible for it to have supported such a vast amount of flesh on land, and it is therefore thought that it was aquatic or semiaquatic in its habits. Some of the dinosaurs, as *Ceratosau'rus* (Fig. 185), were particularly fitted to walk on their hind legs, using the tail as a support. Members of this genus grew to be seventeen feet in height. Hundreds of the footprints of dinosaurs have been found in the sandstone of the Connecticut valley. Fig. 186 shows a well-known dinosaur, *Tricer'atops*, with formidable armature.

One species reached a length of more than twenty feet, and stood eight feet high.

Some of the ancient reptiles (the flying lizards, or pterosaurs, Fig. 187) were capable of flight by means of skin stretched between the front and hind limbs and tail. Most of the bones were hollow and the skull was quite bird-like. Whether these characteristics can be taken to mean that the birds have descended from these flying reptiles is doubtful, though it has been asserted by some paleontologists. It is perhaps more likely that these common characteristics were evolved to meet similar conditions in two different groups, and that we must look farther back to find the ancestors of the birds.

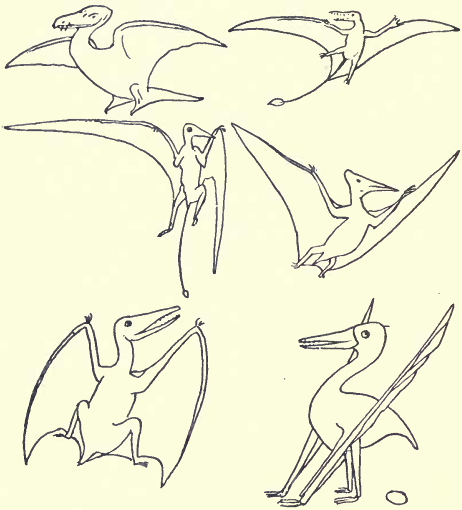


Fig. 187. Restorations of Pterosaurs

(From Seeley's *Dragons of the Air*)

Reptiles which are apparently related to the alligators and crocodiles, and to the turtles and tortoises, have also been found in the rocks of this period, so that these groups are very ancient. Most of the lizards and snakes belong to a later day.

At the close of the Age of Reptiles a great upheaval of land occurred in the west, forming the Rocky Mountain system. After that disturbance, which ranks in importance with the uplift at the close of Paleozoic Time, practically the whole of our continent, with the exception of a strip along the South Atlantic and Gulf coasts, was above the level of the sea (Fig. 188). During the Age of Reptiles a tropical climate extended far toward the poles, but with the upheaval of the great land-masses a gradual lowering of the temper-

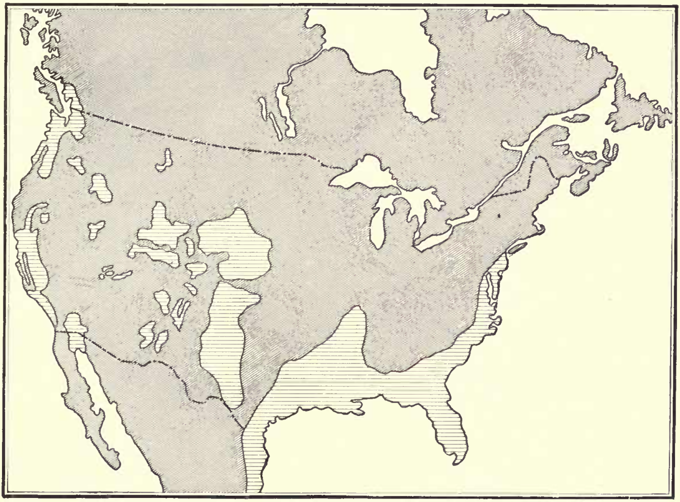


Fig. 188. North America after the Mesozoic Upheaval

(From Dana's *Manual of Geology*)

ature took place, which affected the vegetation. In connection with these changes occurred a wide-spread destruction of species, similar to that which took place at the close of Paleozoic Time. Professor Dana says that no American species of vertebrate and no marine invertebrate is known to have lived both before and after the Mesozoic upheaval.

CHAPTER XXVIII

THE DOMESTIC PIGEON

A hundred wings are dropt as soft as one.
Now ye are lighted — lovely to my sight
The fearful circle of your gentle flight,
Rapid and mute, and drawing homeward soon;
And then the sober chiding of your tone
As there ye sit from your own roof arraigning
My trespass on your haunts, so boldly done,
Sounds like a solemn and a just complaining!

CHARLES TENNYSON TURNER, *On Startling Some Pigeons.*

Habitat and Distribution. The domestic pigeon is known under many varieties, all of which, it is now believed, have been bred by artificial selection from the rock-dove (*Colum'ba liv'ia*, Fig. 189), a bird widely distributed throughout the European north-temperate realm. In its wild state the rock-dove nests in the crevices of rocks, usually along seacoasts. The different domesticated varieties have been still more widely scattered over the earth through man's influence.

External Structure. In the pigeon we can distinguish a *head*, *neck*, *trunk*, and *tail.* All over the body the *skin* is closely set with *feathers.* There are two pairs of appendages: the anterior, or *wings*, are used for flight, and the posterior, the *legs*, for support. The wings consist of an *upper arm*, *fore-arm*, and *hand*, as in the amphibians and reptiles, though the digits are joined together and reduced in number (Fig. 191, 1, 2; a third is shown, though not numbered). The legs (Fig. 191, 3) also show divisions similar to the hind legs of amphibians and reptiles, i.e. *thigh*, *lower leg*, and *foot*, the latter being covered with scales and ending in four *toes*, which bear claws resembling those of the lizard.

The mouth is inclosed by a toothless, horny *beak*, above which are situated the two nostrils, set in a mass of soft, fleshy skin called the *cere* (Fig. 191, 5). The *eyes* are large, and have an *upper* and a *lower eyelid* and a *nictitating membrane.* The external openings to the *ears* are a little behind and

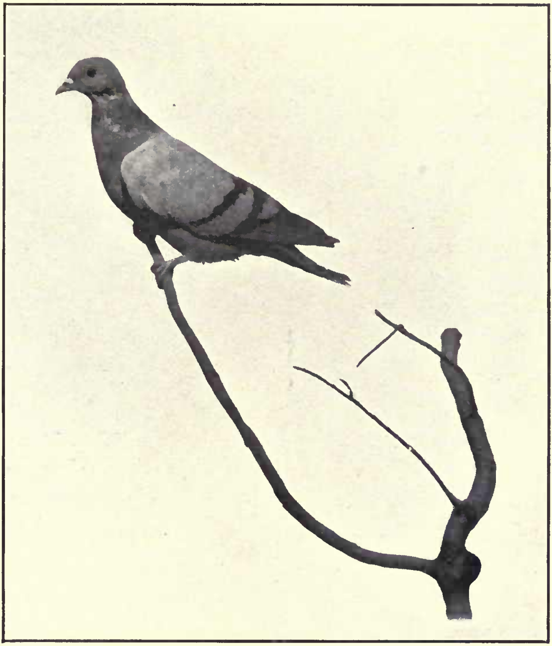


Fig. 189. Photograph of Rock-Dove

below the eyes, and are surrounded with specially modified feathers. At the base of the tail on the dorsal surface is a *gland* (Fig. 191, 4) which secretes an oil for keeping the feathers in good condition.

The feathers are not scattered uniformly over the body, but are arranged in definite tracts separated by areas in which grow only a few hair-like feathers. As an example of a fully developed feather we may choose one of the *contour-feathers* (Fig. 190, *A*) which form the main body-covering. It consists of a hollow base, the *quill* (Fig. 190, *A*, 1), from which arises an expanded portion called the *vane*. Through the center of the vane runs the *rachis* (Fig. 190, *A*, 2), which gives off branches called *barbs*. From the barbs run interlocking structures (*barbules*), bearing hooks which serve to bind the vane into one continuous surface. At the junction of quill and rachis on the under surface of the feather a tuft of down, the *aftershaft* (Fig. 190, *A*, 3), is often found. The wings and tail bear feathers which are contour-feathers of large size and with very firm vanes. Scattered among the contour-feathers are *down-feathers* (Fig. 190, *C*), with which the nestling pigeon was covered, and hair-like feathers, or *filoplumes* (Fig. 190, *B*). Down-feathers differ from contour-feathers in having no barbules, so that the barbs are not held together, but make a fluffy mass. Filoplumes have only a main axis with few barbs.

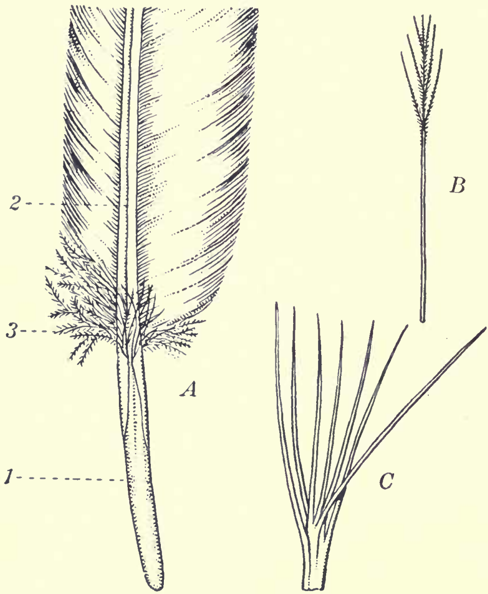


FIG. 190. Kinds of Feathers of Pigeon

A, contour-feather: 1, quill; 2, rachis; 3, aftershaft. *B*, filoplume; *C*, down-feather

The Digestive System. The *mouth* is without teeth. *Salivary glands* opening into the mouth furnish a fluid which assists in swallowing the food. There is a large *tongue* (Fig. 191, 7), pointed at its anterior end. From the *pharynx* there are openings (Fig. 191, 6) to the nostrils and to the ears, as in reptiles and amphibians. A short *œsophagus* (Fig. 191, 8, 10) leads to a large *crop* (Fig. 191, 9), in which the food, consisting largely of grain, is somewhat softened before passing into the *glandular stomach* (Fig. 191, 11) behind it. Glands in the lining walls of the stomach pour out a digestive fluid which serves to further soften the food, which then enters the *gizzard* (Fig. 191, 12), an organ with a yellow, horny lining surrounded by a thick mass of muscle. The gizzard contains small stones swallowed for the purpose of assisting in grinding the food; this process is accomplished by movements of the muscular walls. Beyond the gizzard the *small intestine* (Fig. 191, 13) forms a loop inclosing the *pancreas* (Fig. 191, 17), which discharges its secretion into the intestine through three ducts, one of which is shown in Fig. 191, 18. The *liver* (Fig. 191, 14) is large and opens into the intestine by two *bile-ducts* (Fig. 191, 15, 16). At the posterior end the intestine (*rectum*) passes without change of diameter into the *cloaca* (Fig. 191, 20). The junction between the rectum and cloaca is marked by the presence of two *cœca* (Fig. 191, 19). The *spleen* (Fig. 191, 21) is bright red, and is attached to the walls of the glandular stomach.

The Circulatory, Respiratory, and Excretory Systems. The *heart* is a large, four-chambered organ inclosed in the *pericardium* (Fig. 191, 22). It consists of two *auricles* and two *ventricles*, the latter separated by a complete partition, as in the crocodilians. The circulation is double, and the aërated and non-aërated blood come nowhere in contact, except in the capillaries. The blood is sent to the lungs from the right ventricle, through the *pulmonary artery* (Fig. 191, 29). Freed

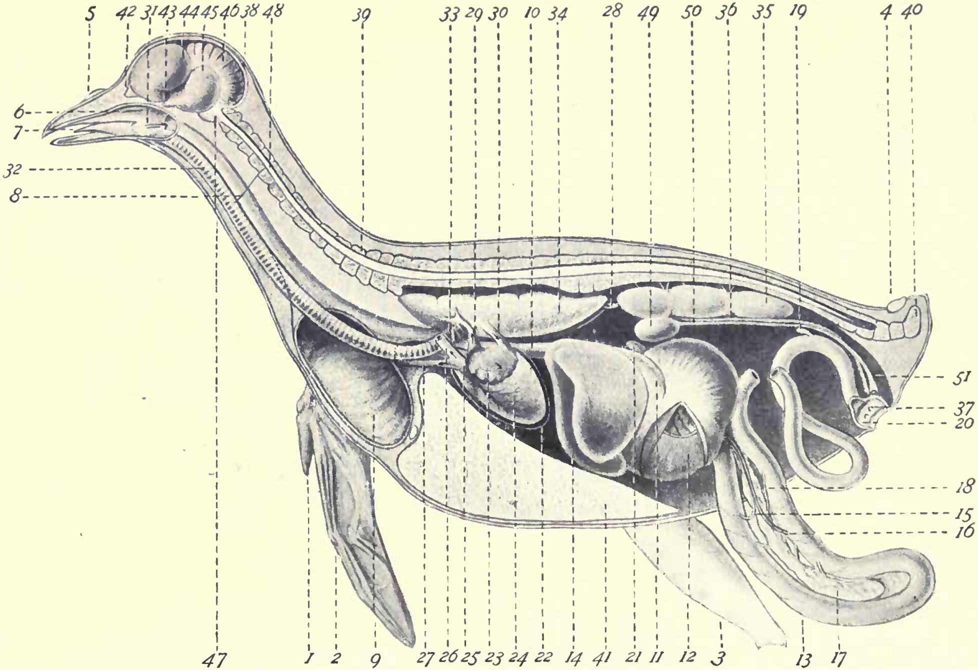


Fig. 191. Dissection of the Domestic Pigeon (*Columba livia*). Reduced

1, first digit (thumb); 2, second digit (a third digit is shown just posterior to the second, though not numbered); 3, leg; 4, oil-gland; 5, cere; 6, posterior nostrils; 7, tongue; 8, œsophagus; 9, crop; 10, œsophagus; 11, glandular stomach; 12, gizzard; 13, intestine; 14, liver; 15, bile-duct; 16, bile-duct; 17, pancreas; 18, pancreatic duct; 19, cæcum; 20, cloaca; 21, spleen; 22, pericardium; 23, left auricle of heart; 24, left ventricle of heart; 25, aorta; 26, left branch of aorta; 27, right branch of aorta; 28, dorsal aorta; 29, pulmonary artery; 30, left branch of pulmonary vein; 31, glottis; 32, trachea; 33, syrinx; 34, left lung; 35, kidney; 36, ureter; 37, aperture of ureter into cloaca; 38, cranium; 39, vertebra; 40, terminal vertebra; 41, st[illegible]m; 42, olfactory lobe; 43, optic nerve; 44, cerebrum; 45, optic lobes; 46, cerebellum; 47, medulla; 48, spinal cord; 49, spermary; [illegible] perm-duct; 51, vesicula seminalis of its carbon dioxide, the blood returns through the *pulmonary vein* (Fig. 191, 30) to the left auricle (Fig. 191, 23), whence it passes to the left ventricle (Fig. 191, 24) and thence into the *aorta* (Fig. 191, 25), which distributes it to all parts of the body. The blood from the body returns to the right auricle, whence it enters the right ventricle, completing its circuit. Lymph circulates through the body of the pigeon in vessels of the *lymphatic system.*

The organs of respiration are the *larynx*, which opens out to the pharynx by a slit-like *glottis* (Fig. 191, 31); the *trachea* (Fig. 191, 32); the *bronchial tubes*, which ramify through the tissue of the lungs, and the *lungs* themselves (Fig. 191, 34). The trachea is kept open by rings of cartilage in its wall. At the junction of the bronchial tubes and trachea is a slight enlargement, forming the *syrinx* (Fig. 191, 33), the organ of voice. The well-known sounds are produced by the vibration of a fold of membrane at this place. Many of the bones are hollow, and there is a system of air-sacs scattered through the body and communicating with the bronchial tubes. By these means the air available for respiration is greatly increased and the weight of the body is lessened. Breathing is accomplished by movements of the muscles of the thoracic region, by which air is driven almost completely out of the lungs at each expiration. The aëration of the blood is very complete, and a high temperature, 37° C. (100° F.) is maintained.

The *kidneys* (Fig. 191, 35) are dark, three-lobed organs fitting closely into cavities beneath the back-bone. The *ureters* (Fig. 191, 36) open into the cloaca (Fig. 191, 37).

The Skeletal System. The *skull* (Fig. 192, 1) is large, with a comparatively large, rounded *cranium* (Fig. 192, 2). The articulation of the cranium with the first vertebra is made by a single *condyle*, as in the reptiles. The vertebræ of the neck or *cervical* region (Fig. 192, 5) are free; those of the *thoracic* region (Fig. 192, 6), *pelvic* region (Fig. 192, 7), and *caudal* region (Fig. 192, 8) are more or less united. There are several pairs of *ribs* (Fig. 192, 13). The caudal vertebræ are terminated by a peculiar bone called, from its shape, the *plowshare* bone (Fig. 192, 9). The *shoulder-girdle* is

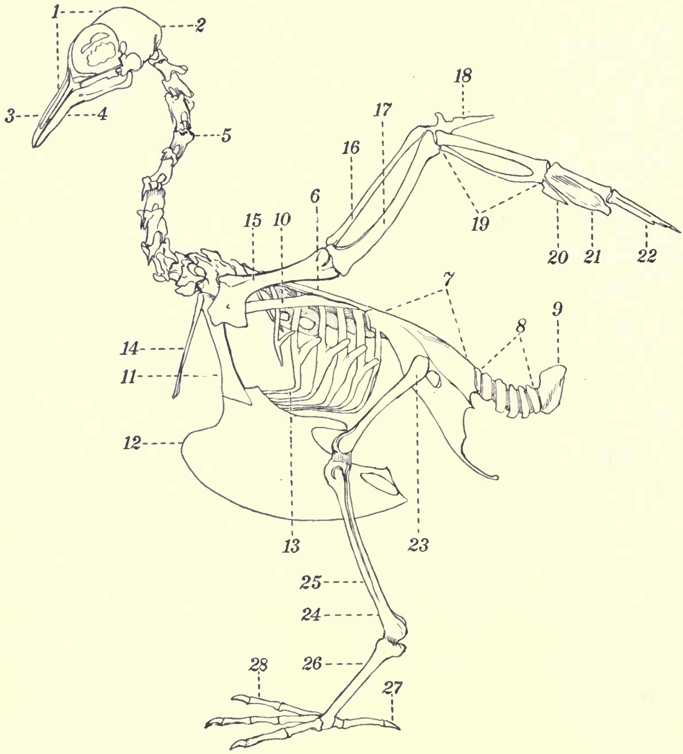


Fig. 192. Skeleton of Pigeon. Reduced

1, skull; 2, cranium; 3, upper mandible; 4, lower mandible; 5, cervical (neck) vertebræ; 6, thoracic region; 7, pelvic region; 8, caudal region; 9, plowshare bone; 10, scapula; 11, coracoid; 12, keel of sternum; 13, ribs; 14, clavicles (wish-bone); 15, humerus; 16, radius; 17, ulna; 18, thumb; 19, wrist and hand bones (carpometacarpus); 20, bone of third finger; 21, bone of second finger; 22, end bone of second finger; 23, femur; 24, tibiotarsus; 25, fibula; 26, ankle and foot (tarsometatarsus); 27, bone of first toe; 28, bone of second toe composed of a pair of narrow *scapulas* (Fig. 192, 10), to which are attached two *coracoids* (Fig. 192, 11), connecting the scapulas and the sternum, and a V-shaped bone, the wish-bone, formed from the union of the two *clavicles* (Fig. 192, 14). A greatly enlarged *sternum* with a prominent ridge or keel (Fig. 192, 12) serves as a surface for attachment of the muscles of flight. The *hip-girdle* is united to the vertebræ of the pelvic region (Fig. 192, 7). A study of Fig. 192 and comparison with the skeleton of the frog (Fig. 165) will make clear in what respects the appendages are different.

The Nervous and Muscular Systems. The *brain* is larger in the pigeon, in proportion to the size of the animal, than in the amphibians and reptiles. The *cerebrum* (Fig. 191, 44) and the *cerebellum* (Fig. 191, 46) are especially large. One of the principal functions of the cerebellum is to control the muscles which bring about the balancing of the body. It is apparent that this is of greater importance in the birds and fishes than in the broader-bodied amphibians and reptiles. The *optic lobes* (Fig. 191, 45), pressed to one side by the large cerebrum, are also well-marked, in correlation with the unusually large eyes and the dependence of the pigeon on the sense of sight. The *olfactory lobes* (Fig. 191, 42) are relatively small, and the sense of smell is not at all keen. The *medulla* (Fig. 191, 47) is bent downwards, as in the reptiles.

The muscular system shows many adaptations to the aërial life of the pigeon. The great mass of muscle by which the downward stroke of the wings is accomplished, occupies almost all the space on the prominent, keeled breast-bone. Its position, low down on the body, makes overturning in the air almost an impossibility. The muscle which raises the wing is also situated beneath the breast-bone, and is inserted on the dorsal surface of the humerus by a tendon which passes through an opening at the shoulder. The tendon thus acts as a pulley in raising the wing. The muscles which bend the toes in perching are so arranged that the mere weight of the bird keeps them contracted, so that even when the pigeon is asleep the toes firmly grasp the perch.

The Reproductive System. The *spermaries* (Fig. 191, 49) are oval bodies attached to the kidneys. The *ovary* of the right side is not developed, but the left ovary is a large organ situated near the kidneys.

Development. Unlike most of our domestic animals, pigeons choose their mates for life. After fertilization the ova or "yolks" pass down the oviduct and are covered with secretions from glands in different regions, first with the white, or albumen, then with a thin membrane, and lastly with a white, limy shell. The eggs are laid in a roughly made nest, and are incubated by both parents in turn for about two weeks, when they hatch. The young bird breaks through the shell by means of a hard structure on the tip of its beak, and makes its appearance covered with a fine down. It is interesting to note in this connection that Darwin says that some of the short-beaked tumbler pigeons, which have been developed by artificial selection, have beaks so short that they are unable to get out of the shell alone, and require therefore to have the help of the pigeon-fanciers. For a few days after hatching the young bird is fed by both parents with a milky secretion afforded by the crop, and called "pigeon's milk."

At first the young are deaf and the eyes are closed, but both sight and hearing are acquired within a few days. Professor T. Wesley Mills of McGill University, Montreal, has found that in newly hatched pigeons the sensibility to touch and pain is very noticeable, and that they are extremely sensitive to heat and cold. The young birds rapidly acquire the power to make coördinated or connected muscular movements, and in a few days the voice develops. The independent life of the pigeon, in some cases Professor Mills observed, began about the thirty-fourth day after hatching.

Relation to Environment. The oval form of the pigeon is well adapted to cleaving the air, and the feathers form a light waterproof covering which serves to retain the body-heat in the rapid flights in the cold atmosphere. A bird has been termed "an ocean greyhound in miniature," and the comparison is not inapt for a creature which possesses such powers of flight and maintains so high a temperature. "It is worthy of notice," say Parker and Haswell, "that birds agree with insects, the only other typically aërial class, in having the inspired air distributed all over the body, so that the aëration of the blood is not confined to the limited area of an ordinary respiratory organ." Other important structural peculiarities are the light, toothless beak, and the small number of digits in the anterior extremities. Still other characters have been referred to in the discussion of the internal anatomy.

The many varieties of the domestic pigeon afforded Darwin much material for his book, *The Variations of Animals and Plants under Domestication.* From their study he obtained many of the conclusions which led to the statement of the principle of natural selection. These domestic varieties differ among themselves in appearance far more than many species in nature. Some well-known varieties are the pouters, fantails, tumblers, and carriers. The pouters are large birds with elongate body and legs, and often with inflated crop and œsophagus. The fantails are known by the extraordinary development of tail-feathers. The tumblers have the remarkable habit of turning somersaults backward in the air from a considerable height nearly to the ground. The carriers have the "homing faculty" developed to such an extent that they are useful as messengers. Though shut within a basket and removed long distances from their home, they have been able to find their way back. Carriers have been used by man for many centuries, notably within recent times at the siege of Paris and in the Russo-Japanese War.

CHAPTER XXIX

THE ALLIES OF THE PIGEON: AVES

> Robins and mocking-birds that all day long
> Athwart straight sunshine weave cross-threads of song.
>
> SYDNEY LANIER.

Definition of Aves (Lat. *avis*, a bird). The pigeon is a representative of the class *A'ves*. Birds are warm-blooded vertebrates adapted as a class to an aërial existence. They are covered with feathers, which are, in their origin, modified scales. Birds breathe by lungs. The young are always hatched from eggs in a form closely resembling the parent. There is remarkable uniformity of structure in the class, making classification extremely difficult.

The following groups, which are some of the most important of the many divisions into which birds have been divided, are not all entitled to rank as separate orders, though often treated as orders.

The Ostrich and Allies. The group *Struthio'nes* (Gr. *struthion*, ostrich) contains the ostrich of Africa, the rheas or South American ostriches, and the emus and cassowaries of Australia, New Guinea, and adjacent islands. They are all large birds with rudimentary wings, and with only two or three toes on each foot. They have no ridge or keel on the sternum, a structure which in most birds serves as an attachment for the muscles of flight; hence the struthious birds cannot fly, though there is evidence that they have descended from ancestors that had functional wings. The legs are large, and the birds run with great speed. Most of them live in open desert places, though cassowaries inhabit forest regions. The eggs are laid in a deep depression in the sand, or in a rough nest in the case of the cassowary. The ostrich is the best known of the group, largely on account of the beautiful wing and tail plumes, which have been used for ornaments from very early times. Ostriches are now raised for the sake of the plumes on "farms" in California and South Africa.

Diving Birds. The group *Pygop'odes* (Gr. *pyge*, the rump; *pous* (*pod*), foot) includes various species of water-birds with

FIG. 193. Photograph of Tern on Nest

webbed or lobed toes. Their scientific name refers to the fact that the legs are placed very far back, so that when standing an erect position is assumed. The tail is very short. The beak is sharp and pointed and fitted for spearing fishes, which constitute a large part of their food. They are expert divers and can swim under water with only the tip of the bill exposed. The nest is generally nothing more than a floating mass of decaying vegetation, attached perhaps to some reeds in shallow water. Our northern lakes and ponds are often visited by the loon, a characteristic diving bird.

Gulls and Terns. The group *Longipen'nes* (Lat. *longus*, long; *penna*, feather) includes long-winged water-birds with sharply pointed or hooked beaks. The colors are usually gray above and lighter below. The three front toes are connected by a web. These birds are strong and graceful fliers, and spend much of their time on the wing. All the members of the group are gregarious, occupying nesting sites on sandy beaches, in marshes, or on rocky shores. They obtain the greater part of their food from the ocean, and are useful as scavengers. Terns (Fig. 193) may be distinguished from gulls by their usually deeply forked tail and straight bill. Gulls are generally pelagic, and they often follow ships for the sake of the refuse thrown overboard; terns frequent the shores of both fresh and salt water. Owing to the forked tail and graceful flight, the terns are often called sea-swallows.

Petrels and Allies. The petrels and their allies are strong-winged pelagic birds, many of which externally resemble the gulls and terns. They may be distinguished from other water-birds by the nostrils, which are inclosed in tubes lying on the dorsal or lateral surface of the upper mandible; hence their scientific name, *Tubina'res* (Lat. *tubus*, tube; *naris*, nostril). The beak is usually strongly and sharply hooked. The food consists of fishes and other small animals which live near the surface of the ocean. The birds often follow ships, like the gulls, to pick up refuse. They occupy various nesting sites along shores. The wandering albatross (*Diomede'a ex'ulans*) of southern oceans is the best-known species. It is the largest of sea-birds, measuring over twelve feet between the tips of the wings. One of the traditions among sailors concerning the albatross is referred to in Coleridge's *Ancient Mariner*. Other members of the group, called stormy petrels and Mother Carey's chickens, are also regarded by many sailors with superstitious dread.

Pelicans and Allies. The members of the group *Steganop'-odes* (Gr. *steganos*, covered; *pous* (*pod*), foot) differ from all other web-footed birds in that all four toes are connected by a web (Fig. 195). They are aquatic, usually marine birds, and feed mainly on fishes. To this group belong the pelicans (Fig. 194), remarkable for the pouch beneath the bill, which is used as a scoop to capture food or as a storage

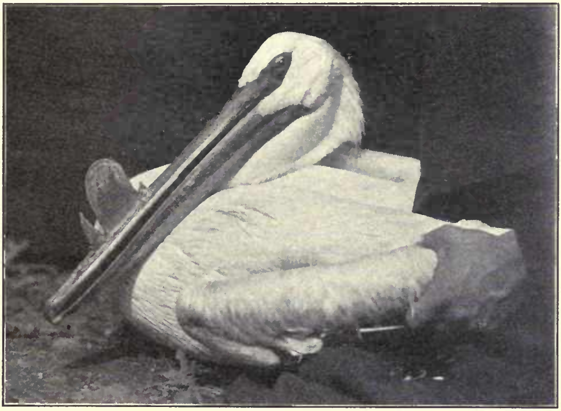


FIG. 194. Photograph of White Pelican

reservoir. There are about a dozen species of pelicans distributed over the world, of which two species, the brown and the white pelican, occur within the limits of the United States. White pelicans (Fig. 194) have the habit of surrounding schools of small fishes and driving them with loud beatings of wings into shallower water, where they can be scooped up in the great pouch and devoured at leisure. The figure shows the peculiar horny outgrowth which appears on the bill of the male at the breeding-season.

Ducks, Geese, and Swans. The group *An'seres* (Lat. *anser*, goose) is made up of water-birds which have the three front toes webbed and the tail comparatively well-developed. The ducks, geese, and swans are included here. The bill is usually flattened and is furnished with transverse tooth-like ridges on both upper and lower mandibles. In the species which frequent rivers and ponds, feeding largely on vegetable food or on small mollusks, crustaceans, and larvæ of insects, these ridges act as a strainer through which the water runs off when the bill is closed, leaving the food behind; in the harbor and sea-haunting, fish-eating species the ridges are useful in holding the slippery food. The nest is usually placed on the ground near the water.

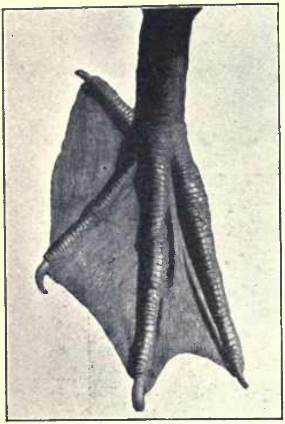


Fig. 195. Foot of Pelican

Several of the swans have the trachea greatly lengthened and looped through the hollow sternum (Fig. 196). By this means they produce their loud whistling or trumpeting note. Wild geese have long excited interest on account of their peculiar manner of migrating in a flock arranged in a long, V-shaped group, keeping up the continual, sonorous "honk, honk." Among the geese and swans the sexes are usually alike, but in many of the ducks the male is specially ornamented with brilliantly colored plumage. Well-known species of ducks are the canvasback duck, dear to the epicure; and the mallard, the ancestor of the common domesticated duck.

Fig. 196. Trachea of Trumpeter Swan

Herons, Storks, and Allies. The birds of the group *Herodio'nes* (Gr. *erodios*, heron), often spoken of as wading birds, are long-legged species, with four toes placed on about the same level, and slightly or not at all webbed. The bill and neck are long and slender. Crests and decorative plumes often ornament the head and neck. Herons haunt the edge

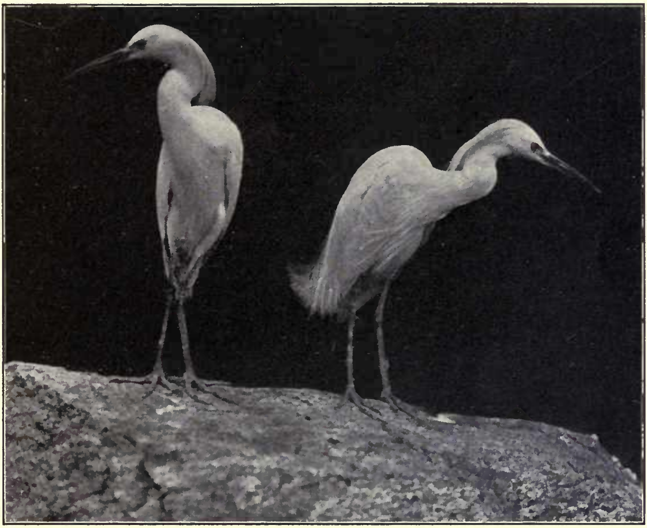


Fig. 197. Photograph of Egrets

of ponds, lakes, and rivers, where they feed on fishes and frogs, which they capture with their long, sharp beaks. They nest in great colonies, usually in trees. The nests are clumsy affairs made of sticks in an untidy mass. One of our largest species is the great blue heron which stands nearly five feet high. Several herons, called egrets (Fig. 197), which have the misfortune to grow beautiful dorsal plumes, or "aigrettes," at the breeding-season, have been practically exterminated by man for the sake of their plumes for women's hats. These birds were formerly common in Florida and along the Gulf coast. Storks are natives of the Old World, frequenting wooded regions or open country. The white stork has been tamed in some countries, where it frequently occupies nesting sites on houses.

Cranes and Allies. Though superficially like the herons, in that they have a long bill, neck, and legs, the cranes and their allies may nevertheless be distinguished from the herons by the elevation of the hind toe above the level of the others. The cranes are scattered widely over the globe, though we have but three species in North America. They frequent marshes and open plains (their scientific name, *Paludic'olæ*, means marsh-inhabitant), and feed on both vegetable and animal food, the latter consisting largely of small reptiles and amphibians. "Erect and tall, they may be seen striding swiftly along with head thrown back, or strutting around their mates; while in spring they often stand in rows and proceed to stalk about in single file, or dance to meet one another with nodding heads, necks advanced, and wings widely outspread. Thereafter they bow toward the ground, jump in the air, and perform graceful antics of all descriptions. The chosen spot for these dances is commonly near water. The male courts his spouse in somewhat similar fashion, and twigs or feathers are often tossed in the air in sport, to be caught again ere they touch the ground" (*Cambridge Natural History*, Vol. IX).

Snipes, Sandpipers, Plovers, and Allies. The well-known shore-birds, included in the group *Limic'olæ*, usually have long, slender legs, with the hind toe, when present, elevated above the others. The scientific name refers to their habitat, (Lat. *limus*, mud; *colere*, to dwell). The bill is usually long and slender and more or less soft, especially at the tip. With their bills these birds probe the mud and sand of pond and river margins and the seacoast for their food, which consists of small crustaceans, worms, and mollusks. The plumage is usually brown or gray, with some white intermixed. During the breeding-season many species give utterance to more or less musical cries. At other seasons a number of species have shrill call-notes or whistles. The eggs are usually laid on the sand in a hollow scraped for the purpose. They are very often protectively colored. Like the domestic fowl, the young are able to take care of themselves from the very first. Their nestling plumage is also protectively colored.

One of the best known is the woodcock, which frequents low, moist, wooded regions. The tip of the upper mandible can be moved upward, so that it is of use in feeling for and seizing worms in the ground. The Wilson's snipe of fresh-water meadows and swamps, and the upland plover of higher and drier pastures, are other familiar species.

Grouse, Quail, Turkeys, Pheasants, and Allies. The gallinaceous birds, *Galli'næ* (Lat. *gallina*, hen), commonly known as scratching birds, have a stout, convex beak fitted for seizing and crushing seeds, which form a large part of their food; the wings are short and rounded, and the short, stout legs have strong toes adapted to scratching. Nearly all species are terrestrial in habit. Here are included the larger part of the game-birds of the world. By far the best known of the group is our domestic fowl, of many races, all of which are descended from the red jungle-fowl (*Gal'lus banki'vus*, Figs. 198, 199) of India, Sumatra, Celebes, and the Philippines.

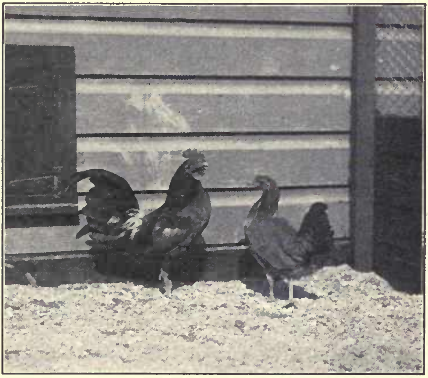


Fig. 198. Photograph of Jungle-Fowl

The best known of the grouse in the eastern United States is the ruffed grouse (*Bona'sa umbel'lus*), usually, but wrongly, called "partridge" in New England. It is about the size of the domestic fowl, and has pronounced black ruffs on the sides of the neck. The male produces a loud drumming sound by beating the air rapidly with the wings. The sound is a call to the female, though it is indulged in occasionally at other seasons than in the spring. The quail-like bob-white (*Coli'nus virginia'nus*) is also, but erroneously, called "partridge" in the southern states. It is a smaller bird than the ruffed grouse, reddish brown in color, and without the ruff about the neck. Neither of these birds should be called "partridge," since that name is already in use for Eurasian species of gallinaceous birds. The same statement is true of the term "quail," which is often applied to our bob-white. The pheasants are magnificently colored birds, native to southeastern Asia and adjacent islands.

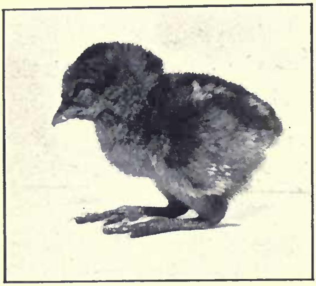


FIG. 199. Young of Jungle-Fowl

Pigeons and Doves. The *Colum'bæ* (Lat. *columba*, a dove) are closely related to the gallinaceous birds, but the nostrils open into a fleshy cere. We have in the eastern United States several species of wild doves, and the passenger-pigeon (*Ectopis'tes migrato'rius*). The latter were formerly present in immense numbers in the wooded regions of the eastern United States. In the early years of the eighteenth century flocks were seen that stretched far across the sky, and which required hours to pass a given point. Farmers were in some places obliged to watch their fields constantly to prevent the birds from picking up the sowed grain. The birds nested in great colonies of thousands, sometimes as many as forty nests in a single tree. Owing to the increased demand for both young and adults as food they were slaughtered indiscriminately and have since been nearly exterminated.

Fig. 200. Head of Golden Eagle

Hawks, Eagles, Owls, and Vultures. The *Rapto'res* (Lat. *raptor*, robber) are generally spoken of as birds of prey, though the term is equally applicable to some members of other groups, the gulls among the long-winged swimmers, for example. The beak is stout, strong, and sharply hooked (Fig. 200); the toes, arranged three in front and one behind, are provided with strong, sharp, curved claws (Fig. 201) with which to seize their living prey, except in the vultures, which feed on carrion. The Raptores possess great powers of flight. The female is larger than the male. The nests are generally bulky structures, composed of sticks and placed in tall trees or on rocky cliffs.

Fig. 201. Claw of Golden Eagle

The red-tailed and the red-shouldered hawks are generally termed "hen-hawks" or "chicken-hawks" by farmers. Though they occasionally levy tribute on the chicken-yard, their propensities in this direction are not so marked as is the case with some of the other hawks which do not sail so conspicuously in the air. Hen-hawks undoubtedly do more good than harm by destroying large numbers of mice and other small mammals. The vultures are, generally speaking, scavengers, or they may attack weak and disabled animals. The black vulture and the turkey-buzzard are invaluable as scavengers in the southern states. They have been protected for this reason, and have become very tame in many places. The owls (Fig. 202) are adapted to nocturnal life. The plumage is soft, making possible a noiseless flight; the eyes are large, and placed so that they look forward.

Fig. 202. Photograph of Barred Owl

Parrots and Cockatoos. The *Psit'taci* (Gr. *psittakos*, parrot) are generally birds of gaudy colors, with a very stout, strongly hooked beak, which is used for climbing, as well as for crushing seeds. They have four toes, arranged two in front and two behind, with strong, curved claws. Most species inhabit forests; they are all good climbers. A great many species can learn to talk, but the red-tailed gray parrot of Africa is considered the best talker. The cockatoos (Fig. 203) are often ornamented with crest-feathers of various colors. They are restricted to Australia, Tasmania, and the Philippines. A New Zealand parrot, the kea (*Nes'tor notab'ilis*), has of late years become carnivorous in its habits, alighting on the backs of live sheep and digging deep into the flesh for the fat surrounding the kidneys. "The propensity is said to have originated from the bird pecking at sheepskins hanging outside country stations." We have only one member of the group in the United States, the Carolina paroquet, and that has been almost exterminated.

Woodpeckers. The group *Pi'ci* (Lat. *picus*, a woodpecker) forms a well-marked assemblage of climbing birds, with two toes in front and two behind (except in the three-toed woodpeckers).

Fig. 203. Photograph of Cockatoo

Woodpeckers have a strong, straight bill, with which they dig into wood for insects, and a long, barbed tongue, spear-pointed at the end, which enables them to draw their food from beneath the bark of trees. The tail-feathers are usually stiff and pointed, and form a support to rest on while the bird is engaged in feeding. The usual coloration in the group is black and white, but red often appears on the head. The nests are made in holes in trees, and the eggs are white in color. By far the greater number of the woodpeckers are beneficial to the farmer, but the yellow-bellied woodpecker, or sapsucker (*Sphyrapi'cus va'rius*, Fig. 204), girdles trees with numerous small holes to get at the sap beneath the bark. The golden-winged woodpeckers (*Colap'tes*) have lost some of the habits of the family, and have descended to picking up part of their food on the ground of fields and pastures.

Perching or Singing Birds. The passerine type (Lat. *passer*, sparrow) is exemplified in more than half the birds of the

Fig. 204. Photograph of Yellow-Bellied Woodpeckers (American Museum of Natural History)

world. The characteristics which serve to distinguish the *Pas'seres*, or perching birds, from other groups are the presence of four toes without webs, placed at the same level, three in front and one behind. The perchers are birds of small or medium size. Among them are included all our well-known songsters. The nesting-habits are various, but a

Fig. 205. Nest of Catbird

great number build complicated and often beautiful nests (Fig. 205) in which to rear their young. The young when hatched are always in a helpless condition, requiring the care of the parent for a time (compare Figs. 206 and 199). The sexes may be alike, or the male may be specially ornamented.

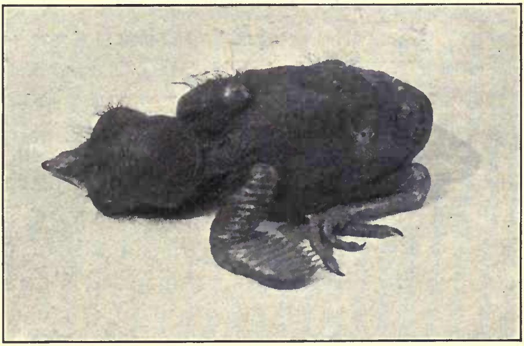


Fig. 206. Young of Catbird

The bright colors of the male are generally believed to be due to sexual selection, and his ability to sing is accounted for in a similar manner. It is worthy of notice that in those cases where song has been developed, bright colors are usually absent. The perching birds are the familiar birds of forest, field, and garden, and are those with which the young student will naturally begin his study in the field. They are so numerous that very few can be referred to here.

The flycatchers (*Tyran'nidæ*, Fig. 207) are pert little birds with a slightly hooked bill, provided with bristles at its base. From some convenient perch they watch for insects, which

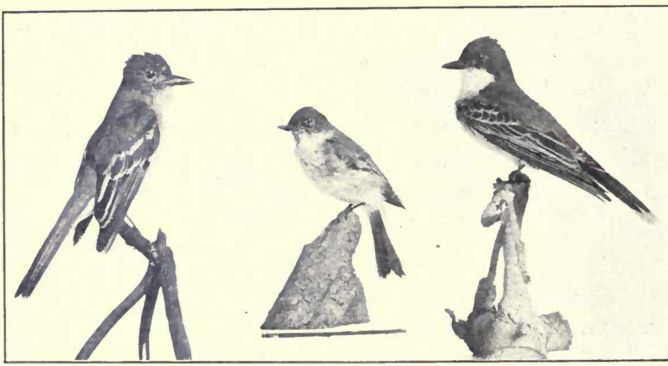


FIG. 207. Photograph of Mounted Group of Flycatchers (American Museum of Natural History)

they snap at on the wing, returning to the perch after each flight. The bristles at the base of the bill serve to entangle insects and make their capture more certain. The brightly colored wood-warblers (*Mniotil'tidæ*), as Mr. Chapman says, "at once the delight and the despair of field students," are also insect-eaters, getting their food almost exclusively from the leaves or bark of trees, though some capture it on the wing, after the manner of the flycatchers.

The vireos (*Vireon'idæ*) are to be found in much the same places as many of the wood-warblers, industriously picking insects from the leaves of trees, or from crevices in the bark.

Vireos are small, greenish-colored birds, which build cup-shaped, hanging nests of plant-fibers, lined with pine-needles and similar material. The white-eyed vireo has the habit of often weaving a piece of newspaper into the structure of its nest; hence it is called "the politician" in some parts of the country. A cast snake's skin is also a favorite object for this purpose.

Our familiar crow and our almost equally familiar blue jay are members of the family *Cor'vidæ*. The family is considered by ornithologists to be unusually intelligent, and by some is even considered the highest bird-group. Closely allied to the crows and jays are the blackbirds and orioles (*Icter'idæ*). In this family is the cowbird, which has the habit of laying its eggs in the nests of other birds, which are usually smaller than itself, and of leaving the egg to be hatched by its foster-parent. A South American cowbird lays its eggs in the nest of another species of cowbird, which does not possess this parasitic habit fully developed, since it sometimes builds its own nest and sometimes lays its eggs in the nests of other birds. The orioles are remarkable for their elaborately inter-woven hanging nests, much deeper than the somewhat similar hanging nests of the vireos.

The finches and sparrows (*Fringil'lidæ*) are the largest family of birds. However varied the members of this group are in form and color, they agree, usually, in the possession of a stout, conical bill, adapted to crushing seeds. The European house-sparrow, often called the English sparrow (*Pas'ser domes'ticus*), is probably well known to dwellers in nearly every town and city in the United States. Introduced from Europe into this country in the neighborhood of Brooklyn, in 1851 and 1852, the house-sparrow has since spread so widely that it may now be said that its conquest of the centers of population in our country is almost complete. It has made itself at home in our city streets, and has managed to pick up a living where another bird would starve to death. Most of the sparrows belong to the fields and hedges, where their brownish coloration serves to make them inconspicuous.

Our American robin belongs to the family of thrushes (*Tur'didæ*). Though not a gifted songster, like some of its near relatives, the robin is dear to all dwellers in the country. With the bluebird and the song-sparrow it shares the honor of being spring's harbinger among the birds in eastern North America. Its habits, song, and call-notes offer an interesting subject for study.

Migration of Birds. The phenomena of migration are especially noteworthy among birds, and the birds of a region may be roughly classified in connection with this habit. Those species which remain in a region all the year are spoken of as *permanent residents* of that region. They may be more or less migratory as individuals; that is, the birds seen in the summer may not be the same individuals that appear in the autumn or winter. The great majority of the birds of the northern hemisphere leave in the autumn to pass the winter in the south, returning in great bird waves in the spring. These birds are the *summer residents* of the region. The summer residents of the eastern United States may pass the winter in the southern states, or they may (like the bobolink) go as far as Brazil. When the great hordes of the summer residents have passed to the south, other birds come down from the north; these are *winter visitants.* Often a bird loses its way, or is blown out of its regular line of travel to other regions; such birds are *accidental visitants* to those regions.

The great migratory movements of birds are fairly regular year after year, and they are participated in by thousands upon thousands of individuals. When the appropriate time comes each species gathers in large flocks, or the individuals separately move off on their long trip. The larger birds, with special means of defense, as the large hawks and cranes or those species with untiring flight, as the ducks, choose daylight in which to travel. Some of the smaller birds which are also rapid and untiring fliers, like the swallows, also carry on their migrations during the day, but most of the smaller birds migrate at night. A foggy night causes the death of large numbers of birds; over fifteen hundred individuals have been picked up at the foot of Bartholdi Statue in New York Harbor after a dark night in the migration period. Attracted by the bright light the birds had dashed against the glass in their swift flight. Birds are exposed to other dangers on their migration-flight. They are fed upon by other animals, and many perish from fatigue, or are blown out to sea, where they fall exhausted into the water.

It is not thoroughly understood how birds find their way over such great stretches of territory. The "fly-lines" of some swallows are ten thousand miles long. The golden plover breeds in arctic America and winters in Patagonia. By some ornithologists (students of birds) the ability to travel these great distances is ascribed to the possession of a sixth sense, — that of direction, which seems to be possessed by some other animals and by savage man. It is supposed that somehow the nervous system registers the ground passed over. Observations by American ornithologists seem to show that the old birds lead the way. Some birds keep up a continual calling to each other, which may help to keep the members of the flock together. In following their migration-routes birds have undoubtedly been helped in some cases by the rivers and coast-lines, and in Europe there are cases where the fly-lines mark submerged coast-lines which the birds followed when the land was above the water. There is such a line between England and the continent, and another across the Mediterranean Sea.

The causes which underlie these great movements cannot yet be stated with absolute certainty. The southerly migration is probably to be associated in general with the failure of the food-supply and the decrease in temperature. It has been stated that the return to the north is due to the desire of the birds to regain their old home, or to their desire for seclusion during the breeding-season. The origin of the habit has undoubtedly to be looked for in the geological history of the world. During the Glacial Epoch (see p. 431) a great part of the northern hemisphere was shrouded in a mass of ice, which came down from the north upon a region which was then almost tropical in its climate. With the onward advance of the ice, the birds, like all other forms of life, were driven south, returning whenever the melting of the ice permitted. Geology tells of many periods of alternate progression and regression of the ice-sheet, with accompanying changes of climate. We have already spoken of the discontinuous distribution of the White Mountain butterfly (see p. 48) as dating from this period. It may well be that the northerly and southerly movements then begun among the birds have been continued till to-day.

Economic Importance of Birds. Leaving out of consideration their value to man as a source of food, birds are chiefly important economically in connection with their destruction of insects injurious to vegetation. Of course not all birds are beneficial in this respect; whether they are beneficial or injurious depends largely on the character of their food. What we know of the food of birds has come not only from the observation of the birds in the field but also from the examination of the contents of their stomachs. The Division of Biological Survey of the Department of Agriculture has performed a most useful task in collecting, tabulating, and publishing observations from all parts of the country, and has recently supplemented this general work by a study of the economic conditions of a single area. The tract chosen was a farm of about two hundred and thirty acres on the Potomac River in Maryland, just opposite Mount Vernon. Here observations were made on the bird and insect life of the farm, with the view of determining not only what the birds really did eat but also what food was available for them at different seasons. So, too, the vertebrate life of the farm, — the mice, poultry, and game, which form a part of the food of some birds; the fruit, both wild and cultivated; the grain and the weeds of the region, and the crops that were planted; all these were considered in the investigation. Besides observations on the living birds, the stomachs of six hundred and forty-five specimens were examined. As in other investigations along the same line, it was found that the largest consumption of insects is to be credited not to the adult but to the nestling. As several broods are raised by many birds each year, and each young bird requires at first considerably more than its own weight of food in a day, the number of insects destroyed in this way is almost incalculable. Of course some beneficial insects are included in this list, but it has been found that those insects which are to be classed as certainly useful, as some of the bees, wasps, and beetles, which prey on pests, make up a very small proportion of the food. The diagram (Fig. 208) shows the proportion of different sorts of food in the young and the adult of the common crow.

Some of the conclusions of Dr. Judd, who studied this region for the Biological Survey, are that "the English sparrow, the sharp-shinned and Cooper hawks, and the great horned owl are, as everywhere, inimical to the farmers' interests and should be killed at every opportunity. The sapsucker punctures orchard trees extensively and should be shot. The study of the crow is unfavorable in results so far as these particular farms are concerned, partly because of special conditions. Its work in removing carrion and destroying insects is serviceable, but it does so much damage to game, poultry, fruit, and grain that it more than counterbalances the good, and should be reduced in numbers. The crow-blackbird appears to be purely beneficial to these farms during the

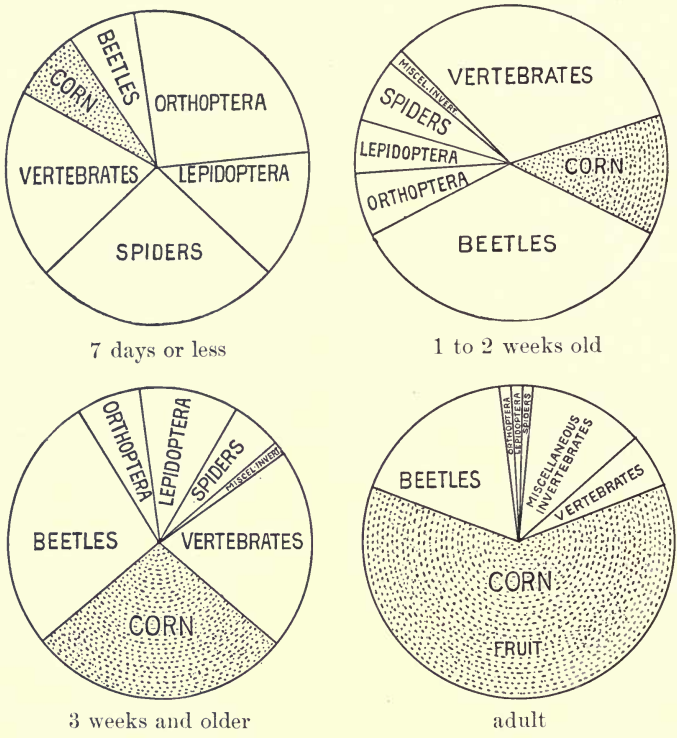


FIG. 208. Diagram of Crow-Food

(From Judd's *Birds of a Maryland Farm*)

breeding-season, and feeds extensively on weed-seed during migration, but at the latter time it is very injurious to grain. The remaining species probably do more good than harm and, except under unusual conditions, should receive encouragement by the owners of the farms. Certain species, such as flycatchers, swallows, and warblers, prey to some extent upon useful parasitic insects; but on the whole the habits of these insectivorous birds are productive of considerable good to man. Together with the vireos, cuckoos, and woodpeckers (exclusive of the sapsuckers), they are the most valuable conservators of foliage on the farms. The quail, meadow-lark, orchard-oriole, mocking-bird, house-wren, grasshopper-sparrow, and chipping sparrow feed on insects of the cultivated fields, particularly during the breeding-season, when the nestlings of practically all species eat enormous numbers of caterpillars and grasshoppers."

Bird-Protection. The first steps toward bird-protection were taken at the instance of the sportsmen, in whose interest laws were passed prohibiting the destruction of game-birds except at stated seasons of the year. These laws were in the interest, too, of the hunter who shot for the market, since they secured for the birds freedom from the molestation of man during the period of bringing up their young, without which protection their extinction would, in many cases, have been only a matter of time. Of late years great interest has been aroused in ornithology, and the value of birds to agriculture or as scavengers has been more generally recognized. People generally have begun to take pleasure in having birds about, for their beauty of form, or color, or movement, and for their song, so that an æsthetic argument has been added to the others. The separate states have shown the effect of this general awakening by the improvement of old laws or the passage of new ones for the protection of the insectivorous song-birds and other birds which have not been proven to be directly injurious. The Audubon societies of the country and the Committee on Bird Protection of the American Ornithologists Union were helpful in arousing a public sentiment which made possible in May, 1900, the passage by the federal government of an act "to aid in the restoration of such birds in those parts of the United States adapted thereto where the same have become scarce or extinct, and also to regulate the introduction of American or foreign birds or animals in localities where they have not heretofore existed." By its provision the preservation of birds is placed under the jurisdiction of the Department of Agriculture. The importation of foreign wild birds is forbidden without permits from the department, and interstate traffic in birds killed in violation of state laws is prohibited. This is the most sweeping act of legislation in favor of birds ever attempted, and it is confidently expected to give them a great measure of protection. As one result of the interest in the study of birds in the schools several states have set apart a Bird Day, which is observed after the fashion of Arbor Day, and oftentimes in connection with it. The first Bird Day was observed in Pennsylvania, May 4, 1894.

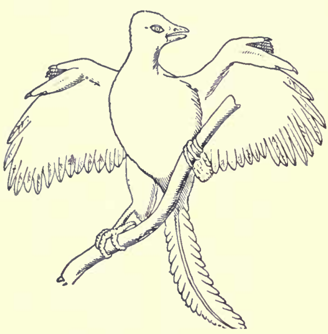


Fig. 209. Archæopteryx. (After Pycraft)

Geological Development of Birds. The earliest remains of birds of which we have any knowledge come from the Age of Reptiles. The oldest of these remains is the famous fossil known as *Archæop'teryx* (Fig. 209), two specimens of which have been found in Bavaria. The ancestry of all known birds is therefore to be traced back, at least so far as our knowledge goes, to these two specimens. Archæopteryx was a land bird about the size of a crow, probably arboreal in its habits, though not necessarily a good flier. It had true feathers, but it was very different from the birds of to-day in that it possessed teeth and a long, lizard-like tail of about twenty vertebræ. These last characteristics are strikingly reptilian, and such considerations point to the fact that the birds developed from the reptiles. As the development was undoubtedly gradual, we should expect to find forms possessing the characters of both groups.

Many bird-remains have been found, especially in the rocks on the eastern slope of the Rocky Mountains, in Kansas and Colorado, which belong to species which lived later in the period. These birds are of at least two different types, differing in the arrangement of the teeth. One group had the teeth set in separate sockets; the other had the teeth in grooves. Some of the birds found in the rocks of this age in New Jersey seem to have been toothless, like birds to-day. It is interesting to note that even thus early the bird type had become quite well advanced, having lost not only the teeth but also the long tail of earlier forms. The time of this period was great enough to permit the development of species of birds with highly developed wings, as well as others with degenerate wings.

In the next succeeding period, to which we shall refer at the close of a later chapter, the birds were all toothless and related to those of to-day. There were woodpeckers, parrots, swallows, cranes, and many others.

CHAPTER XXX

THE GRAY SQUIRREL

Up the oak-tree, close beside him,
Sprang the squirrel, Adjidaumo,
In and out among the branches
Coughed and chattered from the oak-tree.

LONGFELLOW, *The Song of Hiawatha.*

Habitat and Distribution. The gray squirrel (*Sciu'rus carolinen'sis*, Fig. 210) was formerly found all over the wooded region of the eastern United States, and still exists, though in much diminished numbers, wherever its numerous enemies permit. It does not extend farther west than Minnesota and Wisconsin. It prefers those regions where hardwood trees grow, seldom being found in the depths of coniferous forests.

External Structure. The elongate body is covered with a *skin* bearing soft hair, and is clearly divisible into a *head*, *neck*, *trunk*, and *tail*. There are four appendages, the *legs*. The fore legs are used in grasping objects and bringing them up to the mouth, and the hind legs for making the long leaps so characteristic of the squirrel's method of progression in trees. Both pairs of legs show the divisions which we have already noted in the amphibians, reptiles, and birds, and they are provided at the end with digits ending in horny *claws*. The *nostrils* (Fig. 213, 2) are situated at the anterior extremity, just above the mouth. The *eyes* are large, and furnished with an *upper* and *lower eyelid* and a *nictitating membrane*. About the mouth and eyes are long, sensitive hairs called *vibrissæ*. At the back of the head are movable flaps of skin (*pinnæ*, Fig. 213, 1), placed at the opening of the *ears*. The long and bushy tail is useful in a number of ways: it is an ornament; it is useful as a balancing organ in the long leaps from branch to branch; and it serves to keep the squirrel warm in its nest in cold weather.

The Digestive System. The *mouth* is provided with fleshy *lips*, which assist in seizing and holding food. On the ventral

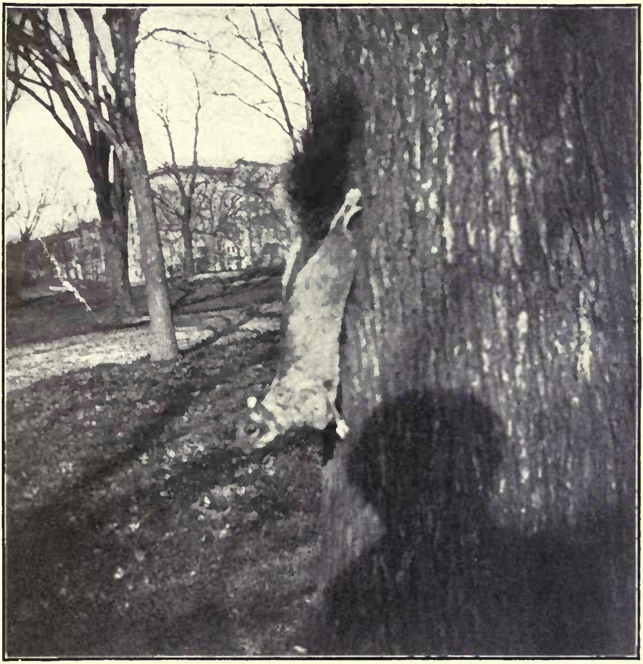


FIG. 210. Photograph of Gray Squirrel

surface of the mouth rests a large, fleshy *tongue* (Fig. 213, 5), with numerous nerve-endings of the organ of taste (*papillæ*) scattered over the surface. Two kinds of teeth are present. The front teeth, called *incisors* (Fig. 213, 4), are long, sharp, and chisel-shaped, and are fitted for gnawing; those in the back of the jaw, separated from the incisors by quite a space, are shorter, broader, and flattened on top, and are fitted for grinding (Fig. 211). The incisors are four in number, two in each jaw; the grinding-teeth in an adult squirrel may be eighteen in number, — four on either side of the lower jaw and five on either side of the upper jaw. Of the grinding-teeth the last three on either side in both jaws are termed *molars*, the others *premolars*. One of the premolars in the upper jaw is very likely to be minute, or even missing, having been shed in early life. The complete dentition can be expressed in a simple formula, using letters to stand for the names of the teeth, and placing the lower jaw below the line, thus:

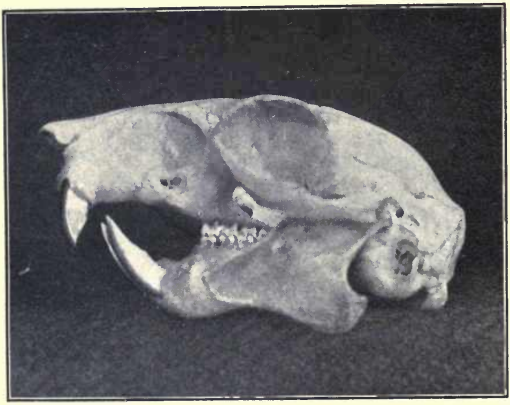


FIG. 211. Skull of Squirrel

$$\text{i.}\,\frac{2}{2}\ \text{pm.}\,\frac{4}{2}\ \text{m.}\,\frac{6}{6}=\frac{12}{10};$$

or, because each side of each jaw is similar to the other,

$$\text{i.}\,\frac{1}{1}\ \text{pm.}\,\frac{2}{1}\ \text{m.}\,\frac{3}{3}=\frac{6}{5}.$$

A tooth contains a *pulp-cavity* (Fig. 212, 4) supplied with blood-vessels and nerves, and surrounded by a mass of firmer tissue, or *dentine* (Fig. 212, 3), which makes up the bulk of the tooth. The dentine is usually covered, where the tooth projects from the gum, with a very hard, smooth substance called *enamel* (Fig. 212, 1); below there is a bony substance, the *cement* (Fig. 212, 2), surrounding the root of the tooth. In the molar teeth of the squirrel the pulp-cavity, which is at first open at the base, as in the case of man (shown in Fig. 212, *B*), becomes inclosed and develops a root (see Fig. 212, *C*), after which all growth of the tooth stops. In the incisors of the squirrel the pulp-cavity persists throughout life, remaining open so that the tooth continues to grow as fast as it is worn away. The enamel is confined to the front surface of the incisors, so that when the tooth is used on hard substances the softer dentine wears away more quickly and the tooth becomes sharper the more it is used.

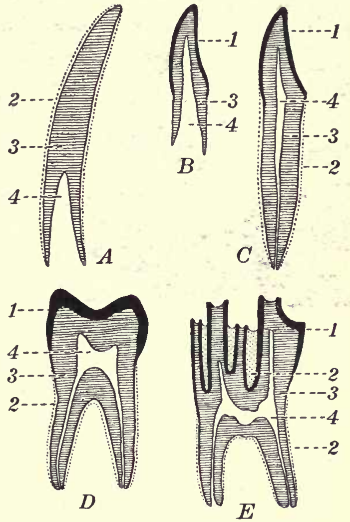


FIG. 212. Sections of Teeth

A, incisor or tusk of elephant; *B*, human incisor during development; *C*, human incisor completely formed; *D*, human molar; *E*, molar of ox; 1, enamel; 2, cement; 3, dentine; 4, pulp-cavity

(From Flower and Lydekker's *Mammals*)

In most fur-bearing animals the lower jaw is articulated to the upper by means of transverse *condyles*, but in the squirrel and its allies the condyles are parallel with the long diameter of the head, thus allowing some backward and forward motion of the lower jaw. The advantages of these special adaptations of the structure of teeth and jaws to the life of a gnawing animal like the squirrel are obvious.

The ducts of four pairs of *salivary glands* open into the mouth. A muscular flap, called the *soft palate*, to distinguish

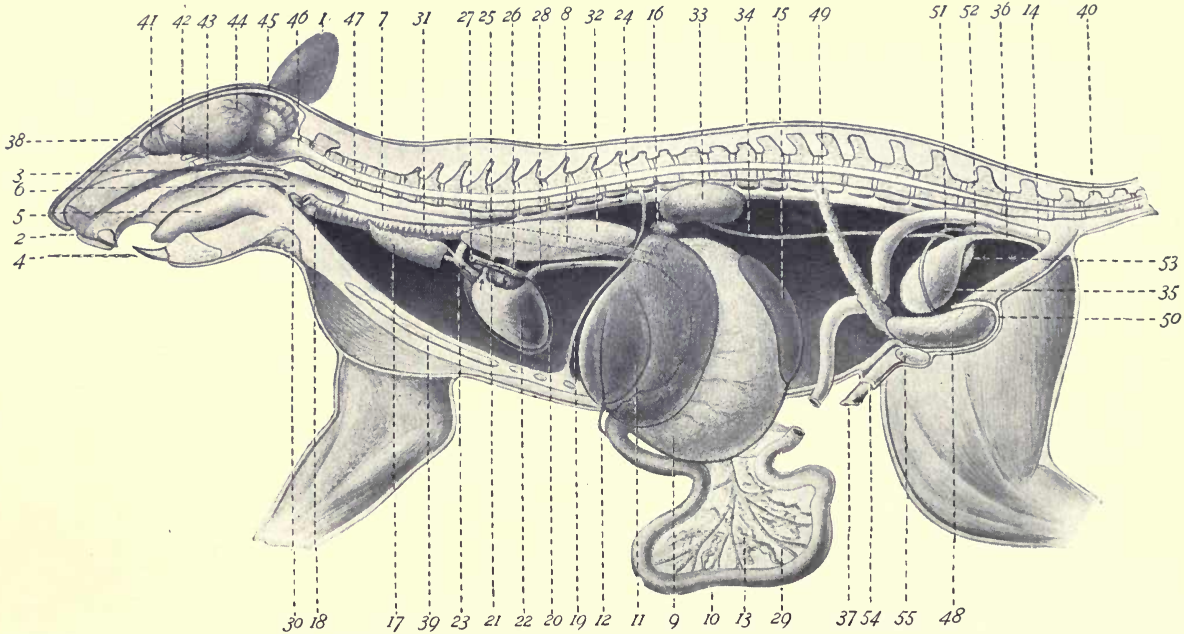


FIG. 213. Dissection of the Gray Squirrel (*Sciurus carolinensis*). × ½

1, pinna of ear; 2, nostril; 3, posterior nostril; 4, incisor tooth of lower jaw; 5, tongue; 6, pharynx; 7, œsophagus; 8, œsophagus, shown in broken outline to indicate its position behind left lung; 9, stomach; 10, small intestine; 11, liver; 12, bile-duct; 13, pancreas; 14, rectum; 15, spleen; 16, adrenal capsule; 17, thymus gland; 18, thyroid gland; 19, diaphragm; 20, pericardium; 21, left auricle; 22, left ventricle; 23, aorta; 24, dorsal artery; 25, pulmonary artery; 26, pulmonary vein; 27, anterior vena cava; 28, posterior vena cava; 29, blood-vessels of intestine; 30, epiglottis; 31, trachea; 32, left lung; 33, left kidney; 34, ureter; 35, urinary bladder; 36, urethra; 37, aperture of urethra; 38, cranium; 39, sternum; 40, first tail-vertebra; 41, olfactory lobe; 42, optic nerve; 43, a cranial nerve; 44, cerebrum; 45, cerebellum; 46, medulla; 47, spinal cord; 48, spermary; 49, mesorchium; 50, scrotum; 51, sperm-duct; 52, uterus masculinus; 53, prostate gland; 54, penis; 55, Cowper's gland it from the roof of the mouth, or *hard palate*, separates the mouth from the *pharynx* (Fig. 213, 6). Imbedded in the soft tissues of the soft palate are the *tonsils*, two small oval bodies the function of which is unknown. The nostrils open posteriorly (Fig. 213, 3) into the pharynx. The Eustachian tubes from the ears enter the pharynx at the sides.

A short, straight *œsophagus* (Fig. 213, 7, 8) leads to the sac-like *stomach* (Fig. 213, 9), passing through a muscular partition called the *diaphragm* (Fig. 213, 19), which separates the heart and lungs in the thoracic cavity from the organs of the abdominal cavity. In the first fold of the intestine is the *pancreas* (Fig. 213, 13), an extended mass of spongy tissue roughly suggesting a bunch of grapes. The *liver* (Fig. 213, 11) is large and is divided into several lobes. The intestine is very long and much coiled. A clearly marked anterior portion, the *small intestine* (Fig. 213, 10), can be distinguished from the posterior portion, or *rectum* (Fig. 213, 14). At the junction of the small intestine and rectum is the *cæcum* (Fig. 214), from which projects a closed finger-like *appendix vermiformis*.

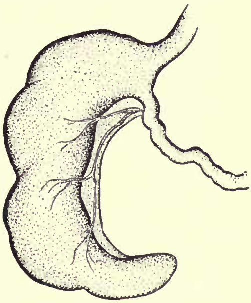


FIG. 214. Cæcum and Vermiform Appendix of the Squirrel

Ductless Glands. Several glands, called *ductless glands* (owing to the absence of a duct leading from them), are present in vertebrates. With the single exception of the spleen (mentioned in each case in the course of the statements concerning the digestive system) they have not been referred to in our brief discussion of the internal anatomy of the classes of vertebrates, but as they show plainly in the squirrel, attention may be called to them at this time. They are, besides the *spleen* (Fig. 213, 15), the *adrenal capsules* (Fig. 213, 16), just anterior to the kidneys, the *thymus* (Fig. 213, 17), and the *thyroid gland* (Fig. 213, 18). Their functions are not thoroughly understood.

The Circulatory, Respiratory, and Excretory Systems. The *heart* is inclosed in a *pericardium* (Fig. 213, 20), and is of the four-chambered type found in the birds. There is a complete double circulation of the blood in the squirrel, as in birds. The lymphatic vessels of the abdomen, called *lacteals*, which carry from the intestine the absorbed fatty materials of food, unite to form a *thoracic duct*, which extends anteriorly and empties into the venous system near the heart.

At the anterior end of the *larynx* is a cartilaginous flap called the *epiglottis* (Fig. 213, 30). The *lungs* (Fig. 213, 32) are larger and more extensible than in the birds, and hang free in the thoracic cavity. Respiration is effected mainly by movements of the diaphragm and the ribs, thus altering the size of the thoracic cavity and causing air to enter and to leave the lungs.

The *kidneys* (Fig. 213, 33) are almond-shaped bodies in the dorsal part of the abdominal cavity. The *ureters* (Fig. 213, 34) lead from them to the *urinary bladder* (Fig. 213, 35), whence the waste products are carried to the surface by the *urethra* (Fig. 213, 36, 37).

The Skeletal System. The skeleton is, in general, built upon the plan with which we have become familiar in the study of the frog, the lizard, and the pigeon. The *cranium* (Fig. 213, 38) is articulated to the vertebræ by two condyles, as in the amphibians. All the *vertebræ* (Fig. 213, 40), except those in the pelvic region, are free.

The Nervous and Muscular Systems. The nervous system is similar to that of the bird, but the *cerebrum* (Fig. 213, 44) is considerably more differentiated. The *muscles*, especially those in the hind legs, form a complex system adapted to strong and rapid movement.

The Reproductive System. The organs of reproduction in the male consist of oval *spermaries* (Fig. 213, 48) and a *penis* (Fig. 213, 54); in the female, of *ovaries* with their *oviducts.*

Development. The squirrel is viviparous. The ovum produced in the ovary passes into the oviduct, where it becomes fertilized, and in that portion of the oviduct called the *uterus* it develops into the young squirrel. The young is born in a condition resembling the adult, though the hair is not comletely formed and the eyes are closed. In the southern states the first of two or three litters appears early in March, and four young are usually produced at a birth. The nest is usually in a hollow tree in the colder portions of its range, and exposed on the branches in the warmer regions. The female keeps the male away from the young during their period of infancy, and feeds them on milk, which is secreted by the *mammary glands* on her ventral surface.

Relation to Environment. When the young have been reared, the winter nest in a hollow tree is usually deserted for a structure of leaves and twigs built high among the branches of a tree. This outside nest is occupied (at least in the colder regions) throughout the summer.

The food of the squirrel in the spring consists largely of buds, especially of the maple and elm. In the summer, fungi and berries are added to the bill of fare, and in the fall nuts form a large part of the diet. The gray squirrel has been accused of varying its vegetable diet with such animal food as the young and the eggs of song-birds, but it is probably not as frequent an offender as the red squirrel, whose bad habits in this respect are well known. The nuts of autumn are gathered and stored in secret places beneath stumps and in hollow trees, and many are separately buried in the ground. Some observers are inclined to think that their sense of smell guides them to the buried food, though it is doubtful if these individual hoards are always located again.

When winter comes on, gray squirrels are likely to be later in rising in the morning, preferring to come out in the warmest part of the day, and on some inclement days they may not venture forth at all. There is no evidence, however, that they truly hibernate.

Gray squirrels have been known to travel in bands from place to place. Of late years, either on account of their much diminished numbers or because of change in the food-supply, we see little of the great migrations which formerly occurred. Many such visitations have been recorded. Pennsylvania was overrun with squirrels in 1749, and a bounty of threepence a head was offered for their destruction. It is estimated that about six hundred and forty thousand squirrels were killed at that time. In their migrations bodies of water were crossed by swimming, though ordinarily squirrels are not lovers of water. The cause of the migrations is probably to be looked for in connection with the scarcity of the food-supply.

The general color of the gray squirrel's fur is protective, and the animal has the habit of flattening itself on the upper side of a horizontal branch, so that it is invisible from below. Of their enemies, the hawks probably give them most trouble. It is said that the red-tailed hawks hunt them in pairs, thus making futile their habit of dodging to the far side of a branch.

Spread over a large area from Maine to Minnesota and south as far as Florida, it is to be expected that the different individuals will vary considerably. In general, it is found that the colors increase in intensity southward and in regions of copious rainfall, while the legs, tail, and ears show a tendency to increase in length. In all parts of their range individuals are sometimes born in which the normal coloring-matter of the hairs is replaced by black pigment, and others in which the pigment is lacking, leaving the fur white.

The black individuals are examples of *melanism;* the white, of *albinism.* Both conditions are quite common among squirrels.

The calls of the gray squirrels to each other may often be heard in the woods, especially in the fall. The "barking," as it is termed, consists of a series of notes ending in a longer snarl. It expresses anger, alarm, or warning. Gray squirrels have sometimes been encouraged to make their homes in city parks, where they soon learn to accept and finally to be largely dependent on contributions of food from human visitors.

CHAPTER XXXI

THE ALLIES OF THE SQUIRREL: MAMMALIA

They say,
The solid earth whereon we tread
In tracts of fluent heat began,
And grew to seeming random forms,
The seeming prey of cyclic storms,
Till at the last arose the man.

TENNYSON, *In Memoriam.*

Definition of Mammalia (Lat. *mamma*, breast). The squirrel serves to introduce the *Mamma'lia*, the highest class of the animal kingdom. Mammals are warm-blooded vertebrates covered with hair. Generally two pairs of appendages are present, the anterior of which are never absent in any member of the class. Mammals breathe by lungs. Teeth are almost invariably present, in the majority of cases occurring in two sets. Mammals bring forth their young alive and feed them on milk, except in the very few cases to be referred to under the *Monotremata* below.

The principal orders into which the class is divided are mentioned in the following pages.

The Duckbill and Allies. The duckbill (*Ornithorhyn'chus anati'nus*, Fig. 215) and two or three species of spiny anteater (*Echid'na*), mammals of the size of a rabbit and found only in Australia, Tasmania, and New Guinea, have many special characteristics. The name *Monotrem'ata* is given to them in reference to the fact that these mammals possess but a single opening (cloaca) through which the contents of the intestine and the urinary and reproductive products pass outward, as in the case of amphibians, birds, and reptiles. Monotremes also stand alone among mammals in the fact that they lay eggs inclosed in a white, flexible shell, reminding one of the egg of a reptile. The duckbill gets its name from its peculiar duck-like beak, which is toothless when the animal is full grown, the teeth being shed after they have been used for a while. The male has a hollow spur on the heel, which is connected with a poison-gland in the thigh. The duckbill is semiaquatic, and lives in burrows in the

FIG. 215. Duckbill
(From Lydekker's *Geographical History of Mammals*)

banks of ponds and streams. Its food consists of mollusks, small insects, worms, and crustaceans. Spiny ant-eaters are inhabitants of elevated rocky districts and feed on ants. They are protected by a covering of spines intermixed with the hairs.

Kangaroos, Opossums, and Allies. The order *Marsupia'lia* (Lat. *marsupium*, a pouch) contains a large number of species, almost all of which are confined to Australia and the surrounding islands. The mammals comprising it are of various external form, but the females of nearly all species have an abdominal fold of skin forming a pouch into which the almost helpless young are placed by the mother when born; they are then carried about with her until they are able to take care of themselves. The kangaroos vary from the size of a rabbit to that of a sheep. The hind legs are developed for jumping. The Virginian opossum (*Didel'phys virginia'na*,

Fig. 216. Photograph of Opossum

Fig. 216) of our southern and middle Atlantic states is the most northern member of the opossum group, many species of which are found in South and Central America. It has the habit of feigning death when in danger of capture, hence the expression, "playing 'possum."

Fossils from the rocks of the latter part of the Age of Reptiles show that marsupials were widely distributed over the earth at that time. Then came the separation of the Australian continent from the land to the north, isolating the marsupial fauna from the larger and more diversified land areas.

The Australian fauna evolved along various lines, producing herbivorous, insectivorous, and carnivorous forms which resemble in outward appearance the members of the higher orders, though they are in reality marsupial in structure. Over the rest of the world, with the exception of America, the marsupials were entirely destroyed and their places taken by more highly specialized types. Marsupials retained a foothold in South America owing to the absence of overpowering enemies, and on account of their adaptation to climatic and

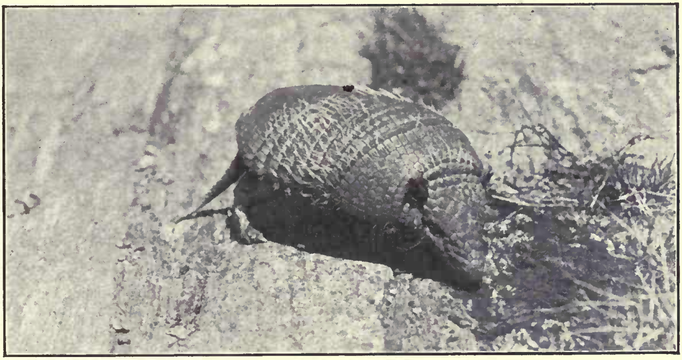


Fig. 217. Photograph of Armadillo

general environmental conditions. They afford an illustration of discontinuous distribution.

Sloths, Armadillos, and Allies. Both terrestrial and arboreal animals are included in the order *Edenta'ta* (Lat. *e*, out; *dens*, tooth). Edentates have incompletely developed teeth, or if the teeth are well developed, they are of simple structure; true incisors are never present. Many members of the order have a covering of scales formed from the hardening of the skin.

The armadillos (Fig. 217) are terrestrial American forms which are protected by the scaly covering just referred to. The tail and head are generally exposed, but the animals can roll themselves into a ball, thus offering a hard surface in every direction.

The sloths of South and Central America are nocturnal, arboreal animals; their natural attitude during the day is hanging from a branch back downward. The hair is gray, but in some species it offers a lodgment for a green alga, a plant of low organization, which gives the hair a green tinge like that of the masses of vegetation of the tropical forest. Sloths rarely descend from the branches of trees.

Whales, Dolphins, Porpoises, and Allies. The whales, dolphins, and porpoises are true mammals, though so adapted to their aquatic life that they seem, on superficial examination, to be fishes. The name of the order, *Ceta'cea*, is derived from the Latin *cetus*, a whale.

Flower and Lydekker, in their *Mammals*, thus review the principal peculiarities of the group: "The external fish-like form is perfectly suited for swimming through the water; the tail, however, is not placed vertically as in fishes, but horizontally, a position which accords better with the constant necessity for rising to the surface for the purpose of breathing. The hairy covering characteristic of all mammals, which, if present, might interfere with rapidity of movement through the water, is reduced to the merest rudiments, — a few short bristles about the chin or upper lip, — which are often present only in very young animals; and the function of keeping the body warm is performed by the 'blubber.' The fore limbs, though functionally reduced to mere paddles, with no power of motion except at the shoulder-joint, have beneath their smooth and continuous covering all the bones, joints, and even most of the muscles, nerves, and arteries of the human arm and hand; the rudiments of hind legs, found buried deep in the interior of the animal, apparently subserve no useful purpose, but point an instructive lesson to those who are able to read it."

Cetaceans are found in all seas, and feed on fishes, crustaceans, and the smaller floating animal life of the ocean generally. They vary from four to eighty feet in length, some of the whales being the largest of existing animals. There is every reason to believe that the group is descended from land-mammals. The whalebone-whales are species without teeth, but with a development of baleen or whalebone in the upper jaw, which acts as a strainer. By means of the closely set, flexible strips of whalebone the small animals on which they feed are retained, while the water is forced out. Several species are found in the Atlantic and Pacific oceans. The sperm-whale (*Physe'ter macroceph'alus*) has a square head,

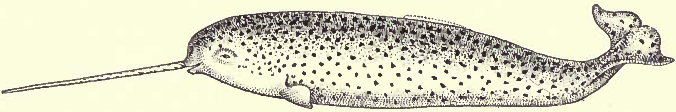


FIG. 218. Narwhal. (After Cuvier)

within which is a cavity containing oil, which on being refined yields spermaceti. The narwhal (*Mon'odon monoc'eros*, Fig. 218) is a smaller species, the males of which possess a single abnormally developed incisor tooth, usually on the left side, which grows into a tusk six or eight feet in length.

Hoofed Mammals. The great assemblage of animals called *Ungula'ta* (Lat. *unguis*, a nail) includes the hippopotami, pigs, camels, deer, the giraffes, antelopes, oxen, goats, sheep, rhinoceroses, horses, and elephants. All these mammals have the toes ending in either a blunt nail or a fully developed hoof, both of which structures are formed from the thickening of the skin of the toes. In ungulates like the cow and sheep there are two divisions in the hoof, and the animals really walk on the tip of the third and fourth digits, the others being much reduced in size. In the horse and its allies this reduction has gone much farther, so that the tip only of the third digit is used for support. The elephants have five toes, each incased in a short nail. The two living species of elephants would undoubtedly be removed to a separate order if fossil forms had not been discovered possessing characters intermediate between these mammals and other ungulates.

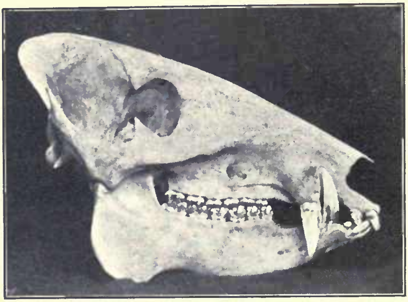


Fig. 219. Skull of Peccary, showing teeth

Ungulates are adapted to a terrestrial life and feed almost entirely on vegetable food. Four kinds of teeth are present, — incisors, canines, premolars, and molars. The first kind and the last two kinds will be recognized from the study of the squirrel; the canines, so named because they are well-developed in the dog (Lat. *canis*, a dog), fill the space between the incisors and premolars. The canines are often elongated to form tusks for defense or for obtaining food (see Fig. 219); the incisors serve to crop the herbage; the molars and premolars are flattened for grinding.

Horns for defense have been developed in many species of ungulates. They are of various sorts. The rhinoceroses (Fig. 220) have one or more median horns, which are composed of a thickened and hardened portion of the skin and hair, covering a short protuberance of the skull. In the giraffes there are one or two pairs of horns consisting of a layer of skin over bony processes of the skull. Neither in the rhinoceros nor the giraffe are the horns ever shed. In the North American pronghorn antelope (*Antiloca'pra america'na*) the horns are branched and consist of a hardened and thickened skin on a bony core. The thickened skin is shed periodically but the core is retained. The horns in true antelopes and in oxen, sheep, and goats, are of similar structure. They are usually found in both sexes and are never shed. In the deer family (Fig. 221) the horns, called antlers, consist of outgrowths of bone covered each year during the period of growth with a sensitive skin called "the velvet." When the annual growth is completed the supply of blood to the antlers ceases and the velvet peels off, leaving the bone bare. After a time the antlers separate from the skull and are shed. In most deer this takes place annually. In some members of the family the antlers remain simple throughout life; in

FIG. 220. Head of Rhinoceros
(American Museum of Natural History)

others they become much branched in successive annual growths (Fig. 221). It is interesting to note that, in a broad way, this was the order of development of antlers in geological time, the earliest deer of which we have any knowledge being without them. Horns and antlers are used in the battles of the males for the possession of the females, as well as for defense of themselves and their band. The presence

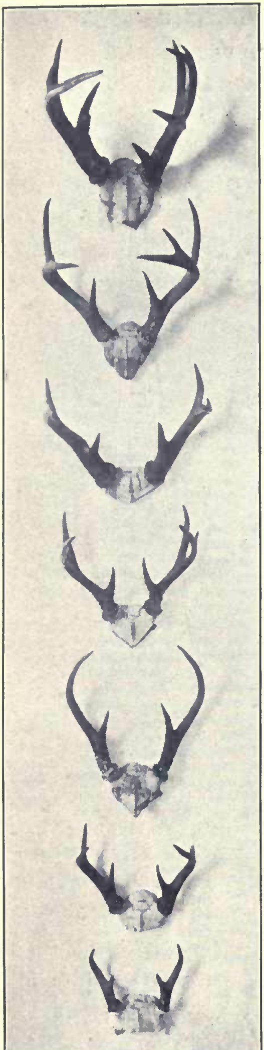


FIG. 221. Series of Antlers (American Museum of Natural History)

of these organs is usually ascribed to the action of sexual selection.

A large number of the ungulates have learned the advantage of coöperation, and live in herds, which possess an organized power of resistance far greater than any individual has. In many cases, especially among the deer, scent-glands are developed on the head below the eyes, and as the sense of smell is extremely acute, notice of the presence of other members of the herd is given by the odor of the secretion from these glands. Often the tail and rump are conspicuously marked with white, showing plainly when the animal is in flight, and probably serving as a recognition or signaling mark.

The structural peculiarities already referred to form the basis for separating the ungulates into three divisions,—those with an even number of toes, as the cow; those with an odd number of toes (one or three), as the rhinoceros and horse; and the long-nosed forms (*Proboscid'ea*), including the elephants. Of the even-toed ungulates the families of camels (*Camel'idæ*), deer (*Cer'vidæ*) and antelopes, goats, sheep, and oxen (*Bo'vidæ*), have the stomach (Fig. 222) divided into a digestive and a non-digestive or storage region, forming a complex organ of several compartments. The food is taken into the first two of these divisions, the *reticulum* or honeycomb bag, and the *rumen* or paunch, where it remains till the animal has finished grazing and has leisure for its digestion. The food is then raised to the mouth in a somewhat softened condition and is there ground between the molar teeth and moistened with saliva, after which it is again swallowed, this time into the *psalterium*, or manyplies, so called from the numerous folds in its lining membrane. The food slowly filters through the manyplies into the true digestive stomach, or *abomasum*. This habit of chewing the cud has suggested the name of ruminants (Lat. *rumen*, throat) for these ungulates.

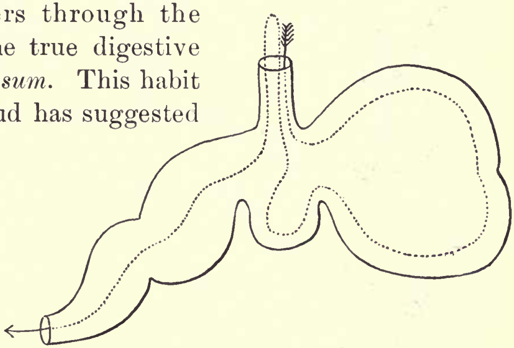


FIG. 222. Diagram of Stomach of Ruminant. (After Wiedersheim)

(Arrows and dotted lines show the course of the food)

Though zoölogists do not feel certain as to the ancestry of the domestic horse (*E'quus cabal'lus*), a recently discovered animal (*Equus przewal'skii*, Fig. 223) of the sandy deserts of Central Asia may be its progenitor. The interesting story of the geological development of the horse is told farther on (p. 428).

Of the Proboscidea the elephants alone require mention. There are two existing species, the Asiatic (*El'ephas in'dicus*) and the African elephant (*Elephas africa'nus*). The latter can be distinguished from the former by its very large ears. The Asiatic species has long been domesticated and many stories are told of its intelligence. The African species was used by the Romans in battle and circus games, but in modern times these animals have been hunted so persistently for their ivory that there is danger of their being exterminated. Steps are now being taken to prevent their complete destruction.

Gnawing Mammals. The *Roden'tia* (Lat. *rodere*, to gnaw) are the most numerous in point of species and are the most widely distributed of all the mammals. Here belong the

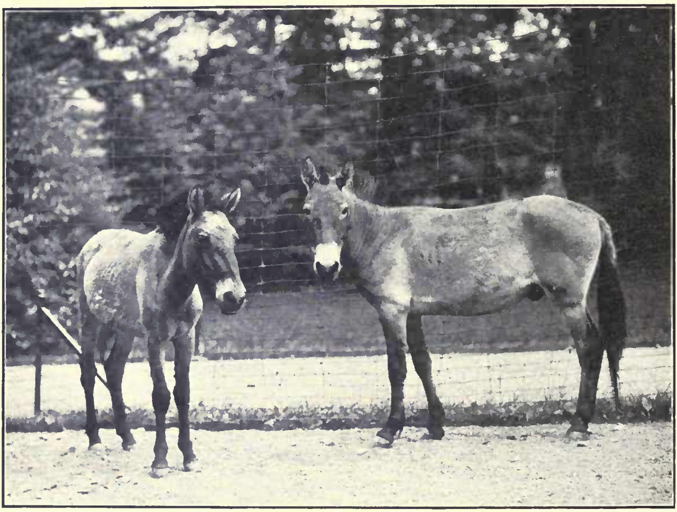


FIG. 223. Photograph of Przewalsky's Horse

hares, guinea-pigs, porcupines, mice, rats, beaver, woodchuck, prairie-dog, and squirrels. Rodents are distinguished by the absence of canine teeth and the presence of chisel-shaped incisors, which grow from persistent pulps (see Fig. 212). They are mostly terrestrial animals, though a few, like the beaver, are modified for an aquatic existence, and others, like the squirrels, for life in the trees.

The hares are distinguished from all other rodents by the presence of a second pair of incisor teeth behind the first pair in the upper jaw. Well-known American species are the cottontail, or gray rabbit, of the East (*Le'pus florida'nus*), the varying hare (*Lepus america'nus*) of the North, and the northern jack-rabbit (*Lepus campes'tris*) of the West. The cottontail is so named from the white tail, which is plainly shown in flight and probably serves as a signaling or recognition mark. The varying hare is a larger and more northern species which takes on a white coat of fur in winter. The northern jack-rabbit also changes to white in the northern part of its range; farther south the change is only partial or entirely wanting. The domestic rabbit is descended from the common rabbit of the Mediterranean basin (*Lepus cunic'ulus*).

The porcupine (*Erethi'zon dorsa'tus*) is a sluggish, stupid animal, which, having spines for protection, relies on them to such an extent that it hunts its food in the daytime,— a habit which most rodents have had to give up (if they ever possessed it) on account of their lack of protection and means of defense against numerous enemies. The squirrels have solved the problem in another way by the development of extreme watchfulness. There is no truth in the oft-repeated statement that the porcupine can shoot its quills, the fact being that, as they are loosely attached, they are likely to come out on slight pressure.

So much has been written on the beaver and its works that its habit of felling trees for its dam or for food, its winter storage of branches or twigs beneath the ice, and the habits developed in connection with its communal life are pretty well known to everybody. In the communal life of the beaver, as among the bees and wasps, instinctive actions are performed with a high degree of perfection. The beaver also has capabilities of meeting new conditions, and it has been credited with a considerable degree of intelligence. It has been hunted so persistently for its fur and scent-bags that it is now almost extinct. The few remaining individuals scattered in isolated colonies seldom dare to raise lodges, but have to be content with a home in the bank of some stream.

Flesh-Eating Mammals. The carnivorous mammals, *Carniv'ora* (Lat. *caro*, flesh; *vorare*, to devour), are the flesh-eaters *par excellence*. The incisor teeth are small and sharp; the canines are generally long, strong, and conical, fitted for tearing; and the premolars and molars are raised into more or less sharp ridges. The toes are sheathed in claws, often fitted for grasping, and in one family, the cats, are capable of being retracted and thus kept sharp by being saved from constant friction. The group has divided along two main lines of development, one adapted to terrestrial, the other to aquatic life. To the first belong the family of cats (*Fe'lidæ*), including the lion, tiger, leopard, lynx, jaguar, and puma; the hyenas (*Hyæn'idæ*); the dogs, wolves, and foxes (*Can'idæ*); the bears (*Ur'sidæ*); and the raccoons (*Procyon'idæ*). To the second division belong the seals and walruses.

The jaguar is a South American cat resembling in general appearance the leopard of Africa, and, like it, an inhabitant of wooded regions, where it spends much of its time in trees. The irregular markings resemble in a general way the patterns of light and shade beneath the leaves of a forest. The markings are usually spoken of as an illustration of aggressive resemblance. The dun-colored lion and the gayly striped tiger are mentioned as similar examples, the one resembling the brown of desert places and the other the vertical shadows of reeds and grasses in tropical jungles. The origin of our domestic cat and dog, like that of some of our other domestic animals, is uncertain, but it is generally believed that the cat is descended from the Egyptian or Caffre cat (*Fe'lis caf'fra*), an African and Asiatic species domesticated by the Egyptians and held in veneration by them; the dog is variously thought to be the descendant of some wild species now extinct, or of one of several wolves or jackals, or a mixture of several species. The great length of time since the dog first became the companion of man, and the numerous races which have arisen, render the question extremely complicated.

Of our smaller wild carnivores none is more generally known and feared than the skunk (*Mephi'tis*), of which there are many species in the United States. Their powerful means of defense is a pair of glands secreting a strong-smelling fluid, which they are able to eject for a distance of several feet. Though they are destroyed by the farmer for robbing his hen-roosts, they are on the whole beneficial, as they feed largely on injurious insects. Those who have observed them most say that they make interesting and cleanly pets, even without the removal of the scent-glands, and that they are not prone to defend themselves except under great provocation. The presence of this means of defense has had its effect upon the skunk's character, insomuch that if a person comes upon it in the daytime it is likely to make no special effort to escape, but goes about its business leisurely, secure in the confidence that it will not be molested. The eastern species are black animals about the size of a cat, with prominent white stripes down the back and a white patch on the forehead. The white markings on the black ground are usually cited as an example of warning coloration. It has been asserted that it is advantageous to the skunk to be thus marked, for if it had a uniform black color, it might be mistaken in the uncertain light for other night-prowlers and be pounced upon and killed by an enemy before it had an opportunity to use its peculiar method of defense.

Among the aquatic carnivorous forms the Alaskan fur-seal (*Callota'ria alasca'nus*) has been the subject of international discussion on account of the value of its fur as an article of commerce. This is a truly migratory species of mammal, bringing up its young on the Pribilof or Fur-Seal Islands in the summer, and going far to sea in the winter. The males do not reach their full size and strength till about the seventh year, and until that age the young males herd by themselves, being forbidden the general herd by the older males. The females mature in two years. Early in May the full-grown males appear at the islands, and the females a few weeks afterward. Each male immediately collects as many females as he can guard, and battles are frequent before the groups are made up. The old males begin to leave the beaches about the middle of July. Seal-hunters are restricted in their operations to killing the young males of three years of age and upwards. This restriction tends to prevent the extermination of the species. The fur is most valuable between the ages of three and seven years.

Insect-Eating Mammals. The insect-eating mammals, *Insectiv'ora*, are usually of small size. The teeth are sharp and numerous, and the molars have sharp points for crushing the bodies of insects. The eyes are often small and hidden in the fur, especially in the forms which, like the moles and shrews, burrow in the ground. The star-nosed mole (*Condylu'ra crista'ta*) is a common American species living in peat-swamps and rich land near ponds and streams. They make great burrows, and the earth thrown up may sometimes make a pile a foot or more in diameter. The name is given from a fleshy filamentous appendage on the nostrils, which is probably used as an organ of touch. Some of the shrews are the smallest mammals known. They generally live in burrows like the moles. They somewhat resemble mice, from which they can be distinguished by the different plan of the teeth.

Bats. The *Chirop'tera* (Gr. *cheir*, hand; *pteron*, wing) are marked off from all other mammals by the possession of wings, which are formed of skin stretched over the bones of the arm, and including also the legs and sometimes the tail.

So well adapted for aërial locomotion have the bats (Fig. 224) become that progress on the ground is almost impossible. The sense of touch is greatly developed not only on the muzzle but on the wings as well, so that the animals are able to avoid obstacles in their nocturnal flights. During the day bats hang themselves up by their legs to sleep in caves and in hollow trees. Some species feed on insects, others on fruit, and some, the vampire bats of Central and South America, feed on blood. The latter have the teeth peculiarly adapted to cutting the skin of animals. The œsophagus is so narrow that no solid matter can pass down it.

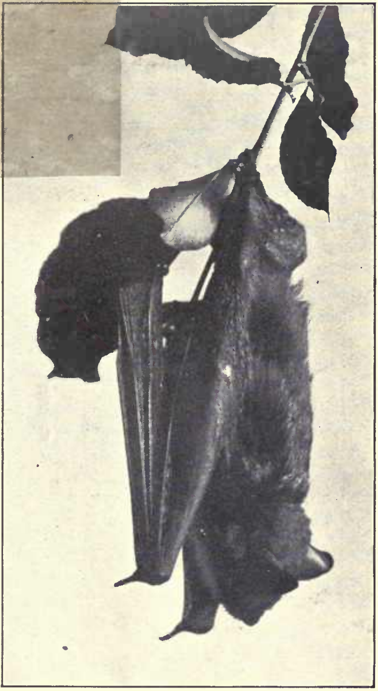


FIG. 224. Photograph of Bat

Primates. The *Prima'tes* (Lat. *primus*, first) include the monkeys, apes, and man. The teeth are generally adapted to a diet of both plant and animal food; the five toes and fingers are separate and are usually provided with nails; the thumb is opposable to the other digits, and the eyes are directed forward.

The spider-monkeys (*At'eles*, Fig. 225) of South and Central America are representative forms of the New World monkeys. They have a long tail, which serves as an organ of prehension. The most man-like of the monkeys are the orang-utan (*Sim'ia sat'yrus*) of Borneo and Sumatra, and the gorilla (*Goril'la goril'la*) and chimpanzee (*Anthropopithe'cus troglod'ytes*) of equatorial Africa. Of these the chimpanzee is the most gentle in disposition and the most intelligent. All these monkeys lead a more or less arboreal life and build nests in trees, where the young are produced.

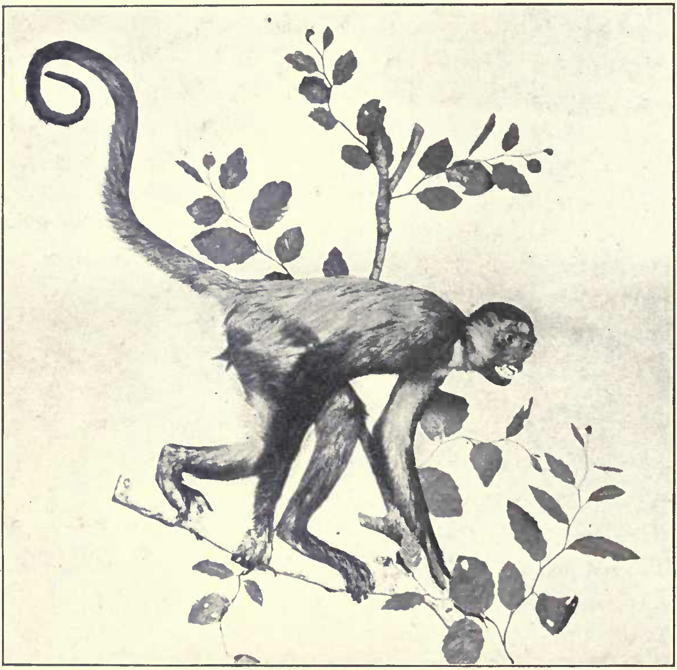


Fig. 225. Photograph of Spider-Monkey
(American Museum of Natural History)

That man belongs zoölogically in the same group with the monkeys is now universally admitted, for in the structural characters upon which classification largely depends, as Professor Huxley pointed out many years ago, he differs less from the apes, which resemble him most, than they do from other monkeys. The principal anatomical characters are the possession of a relatively larger brain-case and less-developed canine teeth, the adaptation of the vertebral column to an erect posture, the greater length of the lower as compared with the upper extremities, and absence of the power to oppose the great toe to the other toes. Some of these differences seemed to have been bridged over by the discovery in 1891–1892 of the fossil remains of an ape-like man, or man-like ape (*Pithecanthro'pus erec'tus*), from the island of Java. These remains point to the existence of an animal about five and a half feet high, with a skull whose profile is "roughly midway between the skull of a young chimpanzee and the lowest human skull," and whose brain-capacity was nearly equal to that of some savage races of to-day. It is now generally admitted that there is but one species of man in the world (*Ho'mo sa'piens*), and the tendency is to group all the different varieties into three races, — the Caucasian of Europe, the Mongolian of Asia, and the Ethiopian of Africa.

Instinct and Intelligence in Mammals. There are some who ascribe to the birds and to the mammals below man mental attributes, including a power of reasoning, differing from the attributes of man not so much in kind as in degree. Some writers separate man quite distinctly in this regard from the lower animals. Careful observation and experiment with animals under conditions as nearly natural as possible is needed before a final answer can be given to questions which are beset with the same difficulties that we have noted in connection with the study of instinct and intelligence in insects.

In order to test whether dogs and cats exhibit any power of reasoning, Professor Thorndike, of Columbia University, experimented upon these animals by inclosing them when hungry in boxes which could be opened by operating some simple mechanism, such as pulling a wire loop or turning a wooden button. Freedom and food outside were the motives to escape. The experiments showed that in all cases the animal instinctively clawed at the side of the box, in the course of which series of movements the door would usually be opened sooner or later. If the animal was replaced in the box again and again, the number of useless clawing actions gradually decreased, till finally the mechanism was operated as soon as the animal was put in the box. If the animal could reason, it would be expected that the box would be opened at once after its first successful attempt; so Professor Thorndike says: "This sort of history is not the history of a reasoning animal. It is the history of an animal who meets a certain situation with a series of instinctive acts; included without design among these acts is one which brings freedom and food."

With this general conclusion Professor C. Lloyd Morgan, in his *Animal Behavior*, agrees. This author says: "As at present advised, therefore, I see no reason for withdrawing from the position provisionally taken up. The utilization of chance experience, without the framing and application of an organized scheme of knowledge, appears to be the predominant method of animal intelligence."

In their mental attributes monkeys seem to occupy an intermediate position between man and the lower mammals. Some of the observations made on this subject have been thus summed by Professor R. Ramsay Wright, of Toronto University. "Sympathy has been observed in many forms. The female gorilla has been said to die of grief when the young is taken away; orangs have come in a body to beg for the corpse of a dead companion, gibbons for a wounded comrade. A female gibbon has been observed to wash the face of her young, a *Cebus* to brush off flies from the face of hers while sleeping, and all monkeys assist each other with the utmost zeal in the search for intruders in their hair. They have been noticed to feed each other, to carry food to sick monkeys, and to adopt orphans. More remarkable than all, a monkey has been seen to throw a rope to a comrade who had fallen overboard. That all monkeys are fond of play, especially when young, is notorious ; they have a keen sense of the ludicrous and enjoy exciting laughter, but they resent being jeered at and may revenge themselves, as in the case of a Cape baboon, who bespattered with mud an officer in his dress uniform who had offended him."

Professor Thorndike closes an article in the *Popular Science Monthly* for July, 1901, in a way which serves to bring out the intermediate position of the monkeys between man and the lower mammals. He says: "In their method of learning, although monkeys do not reach the human stage of a rich life of ideas, yet they carry the animal method of learning, by the selection of impulses and association of them with different sense-impressions, to a point beyond that reached by any other of the lower animals. In this, too, they resemble man ; for he differs from the lower animals not only in the possession of a new sort of intelligence but also in the tremendous extension of that sort which he has in common with them. A fish learns slowly a few simple habits. Man learns quickly an infinitude of habits that may be highly complex. Dogs and cats learn more than the fish, while monkeys learn more than they. In the number of things he learns, the complex habits he can form, the variety of lines along which he can learn them, and in their permanence when once formed, the monkey justifies his inclusion with man in a separate mental genus."

Economic Importance of Mammals. The mammals come into more intimate relations with man than any other group of animals. From them he gets materials for dress, — wool, leather, and furs; food in the shape of butter, cheese, and meat of different kinds. They are his beasts of burden the world over, and they furnish a long line of miscellaneous products such as horn, bone, ivory, perfumes, whalebone, oils, fats, and material for fertilizers.

Geological Development of Mammals. With the upheaval of the Rocky Mountain system at the close of Mesozoic time the North American continent assumed practically its present outline, with the exception of a strip along the south-eastern coast, which was still beneath the level of the ocean (see map, p. 363). In connection with this disturbance of level and the accompanying climatic changes the great reptiles so characteristic of the period became extinct and left the field clear for the development of the mammals. The succeeding period is therefore called the *Age of Mammals*. As we have already seen, representatives of each group of animals have appeared before the age which bears its name, so the first mammals of which we have any knowledge are to be credited to the Age of Reptiles. They were nearly all of small size and allied to the marsupials and monotremes of to-day, — groups which we have noticed as being the lowest of the class.

During the Age of Mammals there were extensive areas of fresh-water lakes in western North America, shown by the shaded areas on the map on page 363. It is from these deposits that much of our information regarding the early mammals of America has been obtained. The American Museum of Natural History in New York City has on exhibition a large series of fossils from this region. Many of the specimens discovered are of generalized structure; that is, they possess the characteristics of several different groups of to-day, without much special adaptation or modification to a particular kind of life or food. It is among such animals that we must look for the ancestors of the species of to-day, for no species of mammal which was in existence in the Age of Mammals has lasted through to the present time.

Of no other animal have we so complete and satisfactory a geological record as in the case of the horse. From fossil remains found in the western part of the United States we are able to trace its evolution from an ancestor (*Protorohip'-pus*, Fig. 226) a little larger than a cat, with four toes on the front feet and three on the hind feet. The figure of Protorohippus is photographed from a water-color by Mr. Charles R. Knight, based on skeletal material at the American Museum of Natural History. The markings are drawn as they are supposed to have existed on the animal. There is

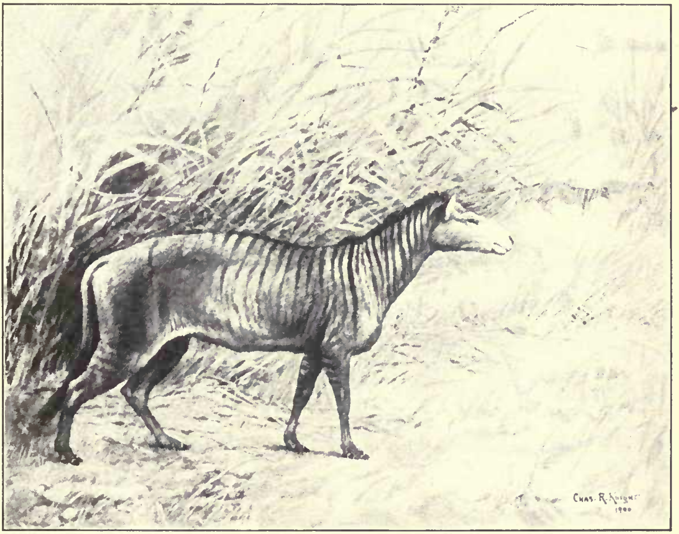


Fig. 226. Protorohippus
(American Museum of Natural History)

reason to believe that the undiscovered ancestors of this early form had five toes on each foot. The transition to the horse of to-day has been accomplished by a gradual increase of size, a reduction in the number of toes, and a reduction in number and an increase of complexity in the teeth. The main steps in the evolution of the bones of the feet are shown in Fig. 227. The changes in the limbs are in the nature of adaptations fitting the animal for rapid locomotion over level, grassy

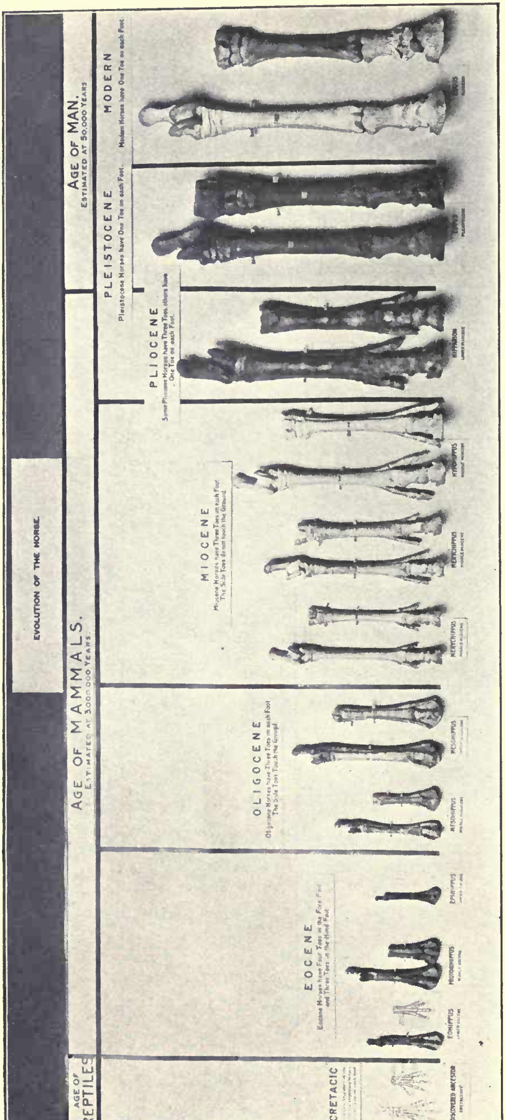


Fig. 227. Evolution of the Horse's Feet
(American Museum of Natural History)

areas. The increased complexity of the teeth makes them more efficient grinding-organs. In the latter part of the Age of Mammals North America was broadly connected with Asia, and the horse is known to have inhabited plains of all the continents excepting Australia. After the horse had reached practically its present state of development (in the early part of the next succeeding period, the Age of Man) it seems to have disappeared entirely from America, owing to causes not thoroughly understood, though generally ascribed to the oncoming cold of the Glacial Epoch. The horse persisted, however, in Europe, and was one of the animals which primitive man domesticated. The various uses to which the horse could be put were gradually learned by man, for Professor Osborn, of the American Museum of Natural History, says there is "abundant proof that man first hunted and ate, then drove, and finally rode the animal." It was reintroduced into America by the Spaniards at the time of their conquest, and soon ran wild.

The carnivores were early represented by generalized types, and later by dogs and saber-toothed cats. The latter get their name from their lengthened canine teeth. Insectivorous mammals, rodents, bats, ungulates of many kinds, and even the primates also occurred, and in the waters of the oceans were found cetaceans of different species.

The Age of Mammals began in North America with a warm climate, as in the case of previous periods, but toward its close frigid conditions began to prevail, probably due to the gradual elevation of the continental land-mass. The oncoming cold produced in the northern part of both America and the Eurasian land-mass conditions so severe that to the period the name *Glacial Epoch* is given. During its continuance all of North America north of a line drawn from New York through Pennsylvania, Indiana, Missouri, South Dakota, Montana, and Oregon, was covered at different times

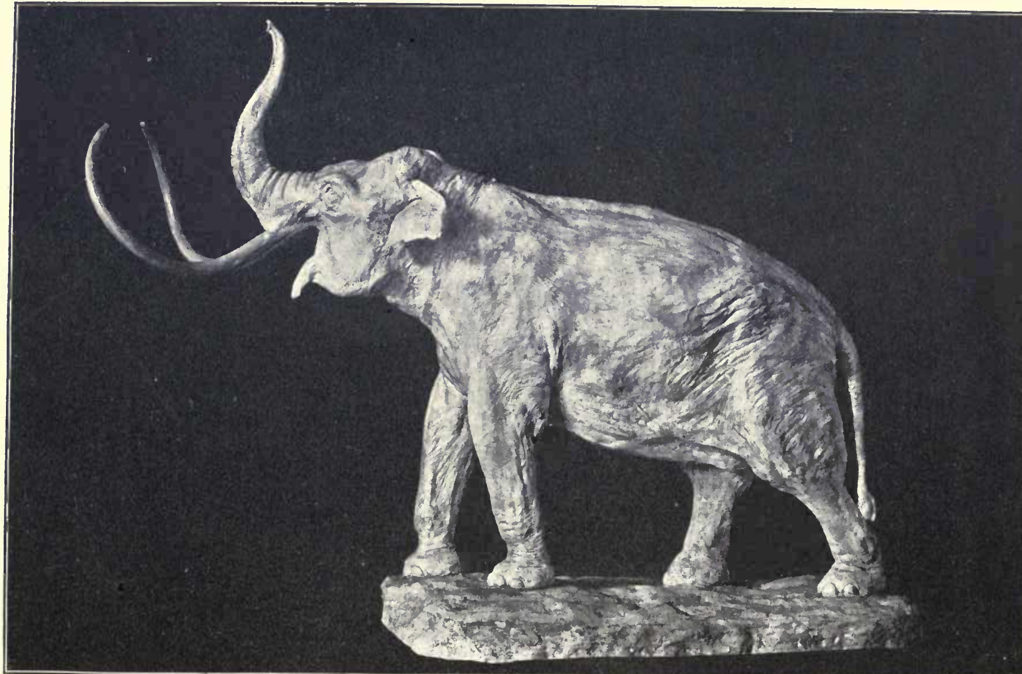


Fig. 228. Photograph of Model of Mammoth
(American Museum of Natural History)

with a layer of ice, which in certain regions grew to be a mile thick over the land, destroying all life or forcing it to migrate southward to escape the rigors of the climate. As there were several invasions and retreats of the ice, there may be said to have been several glacial epochs, separated by long periods of warmer weather, when the animal and plant life could slowly work its way back on the edge of the retreating glaciers. There is a peculiar interest to this period, inasmuch as it introduces the last of the great geological eras, the *Quaternary Period*, or the *Age of Man*.

A conspicuous feature of the mammalian life of the Age of Man was the great size of many of the species. After the opening glacial epoch the climate became mild again, and this seems to have favored the development of abundant vegetation and great mammalian forms. One of the largest and most widely distributed species was the Mammoth (*El'ephas primige'nius*, Fig. 228), a proboscidean larger than the elephant of to-day and covered with a thick coat of hair, an adaptation to cold temperate regions. Its remains have been found frozen in the ice of Siberia, the hair and flesh perfectly preserved. Early man knew of this great mammal, for a drawing of the creature is in existence, made on a piece of its own tusk (Fig. 229). The mastodons were somewhat similar to the mammoths, but fitted on the whole for a warmer climate. There are over thirty species of mastodons known, of nearly world-wide distribution. They have become extinct within so short a time, geologically speaking, that traditions of their existence as living animals occur among men.

The remains of giant edentates have been found in South America. Recent discoveries seem to show that some of them were living within the period of man on that continent, for some of the tribes of South American Indians have traditions respecting these monsters. In Europe and Asia there were lions, hyenas, bears, rhinoceroses, and gigantic ungulates. In Australia, as will be expected from what has been said of the distribution of the group, there were marsupials of various species.

But the great interest of the Quaternary Period centers about man. If it is not yet possible to prove to the satisfaction of every one the existence of man in the Glacial Epoch in North America, it is certain that he was in existence in Europe at that time. It would be interesting to know, if possible, how far distant we should place this period, and

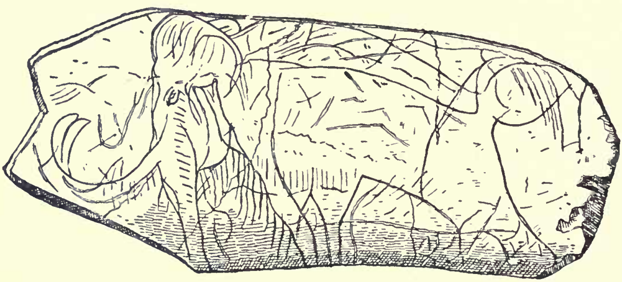


Fig. 229. Primeval Drawing of Mammoth on Mammoth Tusk

(From Lucas' *Animals of the Past*)

where man first appeared on the earth, but to neither of these questions can any satisfactory answer be given. Regarding the time, estimates have been made in various ways, reaching conclusions which vary greatly. A conservative estimate is that the Glacial Epoch began two million four hundred thousand years ago and ended eighty thousand years ago. Regarding the place of man's origin, it has been asserted that his earliest home was Africa, because the great apes, which most resemble him, live there to-day; or that it was somewhere in equatorial regions, where the vegetation is abundant and the climate quite similar throughout the year; others claim that it was on some of the high plains of the temperate zone, like those of Persia and Tibet. After all, the study of the conditions under which he lived is a more important subject than the discussion of either the time or place of his origin.

Primitive man was a savage, living in caves. His principal means of defense, in addition to those with which nature had provided him, were a stone picked from the ground or a bough broken from a tree. At an early stage in his development he learned the use of fire, made clothing of the skins of wild beasts to keep himself warm, and fashioned rude implements out of bone, shell, horn, wood, and stone. In those places where such easily worked metals as copper and zinc were accessible man early learned their use and made from them implements of bronze, a compound of the two metals. From a hunting existence arose the nomadic or wandering life, with property in the shape of herds of domesticated or semidomesticated animals, and the more fixed agricultural condition in which the main dependence for food was on the products of the field. We see people to-day in each of these conditions of existence. Along with the advance in the mode of life has gone a mental and moral evolution as man's conquest of nature has been pushed through wider and wider fields.

CHAPTER XXXII

THE HISTORICAL DEVELOPMENT OF ZOÖLOGY

The present generation finds itself the heir of a vast patrimony of science; and it must needs concern us to know the steps by which these possessions were acquired, and the documents by which they are secured to us and our heirs forever. — WHEWELL, *History of the Inductive Sciences.*

Divisions of the Science of Zoölogy. Zoölogy is the science that treats of animals. It is a sister science of botany, which deals with the plant world. Both botany and zoölogy are branches of biology, the science which has to do with living things. The various ways in which animals may be considered by man give rise to the different divisions of the science of zoölogy. Thus the study of the structure of the organs of animals is *comparative anatomy*, or *morphology;* the study of the functions of the organs (such as nutrition, growth, and reproduction) is *comparative physiology.* The consideration of the mental phenomena of animals is the field of *comparative psychology.* The *geographical distribution* of animals deals with the fauna of the different land-areas; the *geological distribution (paleontology)*, with the animal life of past eras. The study of the relations of animals to each other, to plants, and to their inorganic environment, is *ecology.* Under the name of *bionomics*, Professor E. Ray Lankester has defined this as "the lore of the farmer, gardener, sportsman, and field naturalist." To show the blood-relationships of the different members of the kingdom, animals are arranged in groups, or classified; this division of the subject is *systematic zoölogy.* The consideration of the uses of animals to man is the field of *economic zoölogy.* Finally, the inquiry after the causes of the various phenomena of nature is *etiology.*

Zoölogists are, of course, interested to understand, as far as they can, the phenomena exhibited by the animal kingdom. We have called attention to some of these efforts at explanation in Chapter X.

It will serve to give us the historical perspective which will enable us to better appreciate the great mass of information available for us to-day, if we pass in brief review the main steps in the development of this body of knowledge. We shall gain thereby some insight into the method of scientific research, and shall be helped to see the limitations of our knowledge and to appreciate the problems which are now pressing for solution.

Zoölogy among the Greeks and Romans. In our survey we need not go farther back than the time of the Greeks, for it was there, though in no systematic form, that the beginnings of modern zoölogy were laid. The Greeks' knowledge of animals grew from humble beginnings in an early prehistoric period, and reached its culmination in the philosopher Aristotle (384–322 B.C., Fig. 230). Though the Greeks early showed a lively scientific curiosity and a desire to explain the world of matter and life by ascribing phenomena to natural causes, they generally failed to appreciate the necessity for careful observation of a long series of individual facts before proceeding to explain those facts by reference to a general law.

Aristotle's name is the greatest among Greek scientists partly because he appreciated this need. He laid great stress upon the importance of what is called the *inductive method* in the pursuit of scientific knowledge. This method demands, first, careful observation of a wide range of facts ; second, the study of those facts with reference to each other, to bring out the essential and to eliminate the nonessential elements ; and finally, the explanation of the facts observed, by a statement of the law involved. Aristotle protested against the separation of theory and fact, which invariably occurs when theories are not put to the test of agreement with the facts. "We must not," he said, "accept a general principle from logic only, but must prove its application to each fact; for it is in facts that we must seek general principles, and these must always accord with facts." Though so clearly stated, the principle was forgotten by the world until it was restated by Francis Bacon (1561–1626) in the seventeenth century. To be sure, the English Franciscan monk, Roger Bacon (1214–1292), appreciated the necessity of observation in nature, and himself applied the inductive method in some of his work, but the time was not then ripe for a general appreciation of the importance of the principle.

Fig. 230. Aristotle

Aristotle also owes his preëminence over other Greek writers on natural history to the variety and extent of his own observations, to his voluminous collection of the observations and statements of others, and to his theories of life, which are curiously anticipatory of some features of modern evolutionary views. To refer first to his own observations, it has been computed from Aristotle's works that he was more or less acquainted with over five hundred species of animals, though he was unable to classify them except in a superficial way. His lack of an exact knowledge of anatomy rendered anything like a natural classification impossible. He was, however, familiar with the external appearance of many organs and was able to note the adaptation of organs to different functions. His writings consist not only of his own observations but also of statements about animals taken from every source, and many of these, it must be confessed, seem to us of to-day so plainly untrue and impossible of belief that it is difficult for us to understand how they could have been credited by the philosopher whose vision extended so widely. However, Aristotle's *History of Animals* was the source, as we shall see, from which, for many centuries, much of the natural-history lore of Europe was drawn. The question concerning a disputed point, then, was not, What do the facts say? but, What is written in Aristotle?

It has just been said that Aristotle held views suggestive of those of modern evolutionists. Though he could not have had a sufficient basis of facts from which to draw conclusions, he yet conceived of a complete gradation in nature, beginning with the inorganic world, passing through the plants to animals, and ending with man. Like others of his time, Aristotle believed in the development of living from non-living matter (spontaneous generation), and he pictured the change as taking place directly, even with some of the higher animals. With much that is false and mistaken, enough of value and brilliancy remains in the work of Aristotle to entitle him to be called the founder of zoölogy.

Passing mention should be made of one other Greek, the philosopher and physician Galen (born A.D. 130). He deserves credit for being the first to insist that medicine must rest on a knowledge of anatomy and physiology. Dissection of the human body being forbidden, he examined the bodies of monkeys and swine as being near to man in structure. His work represents the highest attainments of Greek medicine.

The genius of Rome was not manifested along the line of biology, and there is in the whole course of Roman history no really great name in this science. We may mention, however, the Roman naturalist Pliny (born A.D. 23), who lost his life while attempting to approach Vesuvius during the great eruption in A.D. 79, which overwhelmed the cities of Herculaneum and Pompeii. Pliny was not so much an original observer as a voluminous writer and collector of the opinions of others. His books are a great storehouse of the facts and fancies of antiquity.

The Middle Ages. History tells how Greece was conquered by Rome, to what height Rome attained, and how the downfall of the Western Roman Empire in A.D. 476 brought to a close the ancient history of Europe and ushered in a new civilization built on the ruins of the old. The period from the fifth to the sixteenth century is usually spoken of as the Middle Ages. In the early part of this period (from the fifth to the eleventh century, often called the Dark Ages) the many wars left little time for the pursuit of science. The habit of observing natural phenomena and the desire to seek an explanation had given place to a slavish acceptance of the statements of others. Blind adherence to authority reigned everywhere. In all this time no new fact of importance appears in the history of our science; no great original student of the subject was born.

While Europe was in this condition of darkness the Arabians, originally a shepherd race, stirred to national life by their prophet, Mohammed (born A.D. 570 or 571), began a long series of wars, which resulted in the conquest of a large part of western Asia and northern Africa. They even pushed their way into Europe, conquering the whole of the peninsula of Spain, with the exception of a few mountainous districts in the north. During the period of their greatest power the Arabians alone, of all the races of Europe, kept alive the spirit of science. They preserved many classical works from destruction, especially those of medicine, by translating them into Arabic. The power of the Arabians came to an end in Europe in 1491, when Granada, their last stronghold, was torn from their grasp by Ferdinand and Isabella.

During the closing centuries of the Middle Ages many events prepared the way for the new interest in science characteristic of the sixteenth and seventeenth centuries. The many political adjustments of the period molded the nations of Europe into much the same form as we know them to-day. The application of the mariner's compass to navigation made voyages to new lands possible. America was discovered by Columbus; Magellan's ship sailed round the world. As a result of the general intellectual awakening the bonds of authority were weakened and men began to think for themselves. Printing was invented, and then followed a wide dispersion of the knowledge of the ancients. Universities were founded, to which flocked students from all over Europe, eager to drink in the new learning.

Zoölogy of the Sixteenth Century. With the sixteenth century we are fairly adrift on the stream of modern science. One of the earliest investigators was Andreas Vesalius, born in 1514 at Brussels. He became interested in anatomy while only a boy and studied the human body from dissections, though often experiencing considerable difficulty in getting material. In 1540 he became professor of anatomy in the University of Padua, in northern Italy, and two years later, when twenty-eight years of age, he published his *Great Anatomy*, illustrated with woodcuts by the best Italian artists of his time. Having had the advantage of making dissections, he was able to point out errors in the work of Galen, who had been forced to study the lower forms. With Vesalius and his contemporaries modern anatomy may be said to have begun.

Konrad von Gesner (1516–1565), born at Zurich, Switzerland, had a wide interest in natural history. He was a poor boy, left an orphan, and his early life was one constant struggle with poverty. Conquering all difficulties, so great was his enthusiasm for science, he rose to be professor of natural history in his native city. He made collections of animals and plants, and published (1551–1558) a great *History of Animals*, in which he described all the animals then known, with statements concerning their structure and habits, some details of their physiology, and their economic importance. This was the first comprehensive work on natural history since the time of Aristotle.

Zoölogy of the Seventeenth Century. To William Harvey (1578–1657), an Englishman who studied at Padua under a pupil of Vesalius, we are indebted for the first accurate statement of the circulation of the blood in man. Galen had shown the existence of blood in the arteries, and Harvey's professor at Padua had confirmed the existence of the valves in the course of the venous circulation, pointed out by a still earlier investigator; but it was left to Harvey's painstaking observations to follow the course of the blood from the heart to the lungs, from the lungs back to the heart, and thence all over the body. Harvey's discovery was made in 1614 and published in 1628, after his return to London, where he practiced as a physician. Like many another discovery in science, it at first aroused hostile criticism. From this period the rise of animal physiology may be dated. Harvey also studied the development of the chick in the egg, and may be said to be the founder of modern embryology. Of course he did not understand the egg as well as we understand it to-day, since he believed in spontaneous generation.

In the early part of the seventeenth century (1609) Galileo used the telescope, bringing distant worlds within our nearer view. What the telescope was to astronomy the microscope was to zoölogy. The invention of the microscope, about 1600, is usually credited to Zacharias Janssen, a Dutch spectacle-maker; it was used in the study of animals by Malpighi (1628–1694), an Italian anatomist, about 1661. Among other subjects he studied the capillary circulation, which was beyond the power of Harvey with only his simple lens. In England the labors of John Ray (1628–1705) added greatly to our knowledge of animals. Ray was the first to define the use of the word "species." He laid the foundations of systematic zoölogy.

Fig. 231. Linnæus

Zoölogy of the Eighteenth Century. To Linnæus (1707–1778, Fig. 231) is due the credit for the invention of the binomial nomenclature. Before this time there had been the greatest confusion among naturalists as to the names of animals and plants. Not only were the names themselves cumbersome, but there was no uniformity in their use. Linnæus also saw the need of groups higher than species, and he put classification on a more exact basis by recognizing and defining six classes of animals, —

mammals, birds, amphibians (including reptiles), fishes, insects (including all arthropods), and Vermes (including mollusks, worms, echinoderms, cœlenterates, and protozoans). He believed in the fixity of species, teaching at first that there are as many species of animals as were created in the beginning. Subsequent editions of his *System of Nature* (first published as a pamphlet in 1735) showed slight modifications of this view, but on the whole his influence was in behalf of the idea of the fixity of species.

Buffon (1707–1788) was destined to exert as great an influence on zoölogy as did Linnæus, but in a different field. Buffon's studies were widely extended over nature. His *Natural History* is a popular account of the animal kingdom most interestingly written. It was read very generally and did much to popularize the subject. Buffon was one of the first to attempt an explanation of the facts of the geographical distribution of animals, and he is considered the first of the great pioneers of modern evolution. Professor Osborn, in his history of the development of the evolution idea, *From the Greeks to Darwin*, says: "It is interesting to contrast these two great men [Linnæus and Buffon], one the founder of the view of classification as a fixed system of the divine order of things, and the *ne plus ultra* of botany and zoölogy; the other the founder of the directly opposed view of classification as an invention of man, and of the laws governing the relation of animals to their environment as the chief end of science." As might be expected at this period Buffon was not an unqualified evolutionist but wavered between views such as Linnæus held and a belief in the mutability (liability to change) of species.

One of the earliest writers in the field which we have termed ecology or bionomics was the English clergyman, Gilbert White (1720–1793), the author of *The Natural History and Antiquities of Selborne.* Though, as Professor J. Arthur

Thomson points out, White was "the prototype of the better class of modern amateurs," still the out-of-door study of animals "rarely attained either dignity or definiteness until Darwin demonstrated its importance."

Animal electricity was discovered by Galvani (1737–1798), professor of anatomy at Bologna. His attention is said to have been called to the subject by his wife. She was preparing frogs' legs for the table near an electric machine in operation, and noticed that when the legs were touched by the knife they twitched violently.

Zoölogy of the Nineteenth Century. The science of zoölogy developed so rapidly from the beginning of the eighteenth century that it will be impossible now to do more than call attention to a very few of the most important discoveries and the men to whom they are accredited. A dominating figure in the early part of the nineteenth century was Georges Cuvier (1769–1832), a French naturalist whose influence was exerted along many different lines. By his studies of fossils, recognizing them as the remains of animals of past times, and related to the animals of to-day, he founded paleontology. He also stated the principle of the correlation of parts,— a conception which pictures the animal as a unit rather than a fortuitous collection of separate parts. While he undoubtedly carried the principle beyond its legitimate limits, there can be no question as to its important influence on the history of zoölogy. Cuvier recognized the importance of anatomical structure as a basis for classification. He also knew a second basis in paleontology, a fact just referred to. Cuvier divided the animal kingdom into four groups,—Vertebrata, Mollusca, Articulata, and Radiata.

During the nineteenth century important discoveries paved the way for a better understanding of the minute structure of the animal body and the physiology of its units of structure, the cells. In 1838 Schleiden showed that plants were made up of very small parts called cells, and the next year Schwann made a similar discovery with respect to the animal body, thus laying the foundations for the "cell-theory." The main propositions involved in the cell-theory, as stated by Professor Thomson, are, first, that all organisms are either built up of single cells or combinations of such cells; second, that all organisms begin life as a single cell, which, in the case of the many-cell organisms, gives rise to a more or less complex body; and third, that the function of a multicellular organism can be expressed in terms of the activities of its component cells. Though the third proposition may now require some modification, the cell-theory proved an invaluable unifying conception in biology. In 1846 the word "protoplasm," originally used in a different sense, was applied by von Mohl to the substance inclosed by the cell-wall in plants; and in 1861 Max Schultze established the essential identity of protoplasm with the life-substance in the animal cell, which had been called sarcode. Embryology was broadened through the influence of von Baer (1792–1876), who, in 1827, described the primary germ-layers in the vertebrate embryo. We owe the appreciation of the importance of the embryological basis of classification to von Baer.

The nineteenth century was prolific in experiments to test whether there could be spontaneous generation of organisms, and a war of discussion was waged between those who supported the idea and those whose experiments seemed to show that all the living organisms experimented upon came from preëxisting life. The experiments of Francesco Redi (1626–1697) in the seventeenth century had shown that maggots did not appear in decaying meat if flies were prevented from having access to it, and the discussion took a new turn about the possibility of the spontaneous generation of the animalculæ (such minute animals as the infusorians and rotifers). Some of the earlier experimenters did not succeed in reaching the truth on account of their carelessness in operation, but it was finally shown that no animalculæ appeared in water which had been boiled thoroughly and sealed so that no germs could enter. The final conclusive experiments were those of Pasteur (1822–1895) about 1860, and those of Tyndall (1820–1893) a few years later.

An important step in paleontology was made when Boucher de Perthes, in 1836, found flint axes in northern France so far beneath the surface of the ground that it pointed toward a greater antiquity for man than had hitherto been believed. Though combated by many, the truth finally prevailed, and man's presence in Europe was proven at least as far back as glacial times.

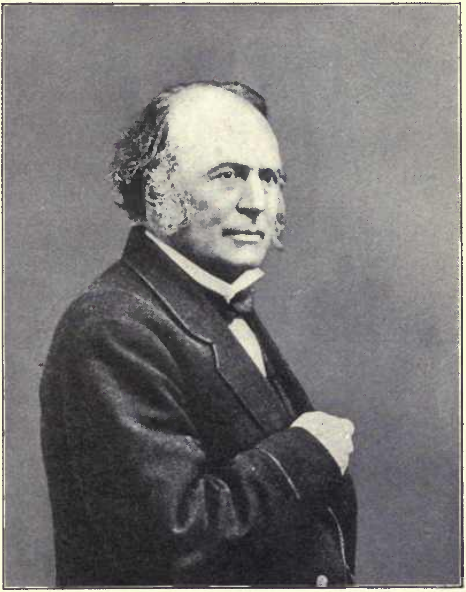


FIG. 232. Louis Agassiz

Louis Agassiz (1807–1873, Fig. 232) is famous both as an investigator along many different lines and as an inspiring teacher. He was born in Switzerland, near Lake Neuchâtel, and after study in Europe came to America at the height of his reputation in 1846, where he remained during the rest of his life. He became connected with Harvard University in 1847, and the Museum of Comparative Zoölogy at Cambridge, Massachusetts, is a monument to his enthusiasm and devotion. Agassiz' researches cover a wide field, but perhaps his most important contribution to zoölogy is his work on fossil fishes. It is interesting to note that he was the last great zoölogist to hold out against the evolutionary views which came in with the epoch-making work of Charles Darwin.

We must go back for a moment to consider the beginning of the evolutionary views, which, as we have said on page 101, are accepted in some form by practically all scientific men to-day. Professor Osborn in the volume referred to in the discussion of Buffon says that the Greek philosopher Empedocles, of Agrigentum (495–435 B.C.), may justly be called the father of the evolution idea, since he conceived of animals and plants as arising through the fortuitous play of the great forces of nature, love and hate, on the four elements, fire, water, earth, and air. First appeared the plants; later, after many trials, the animals, — the latter not as complete individuals but as parts of individuals. From the chance meeting of parts came monstrous forms incapable of propagation. After ceaseless trials Nature produced the fit and perpetual tribes. Here is the germ, according to Professor Osborn, of the survival of the fittest or of natural selection.

Aristotle's conception has already been referred to. In one form or another, evolutionary views were put forward by philosophers and naturalists during the long period which intervened between Greek thought and the time of Buffon. These views, while interesting historically, need not detain us now, nor can we stop to outline further Buffon's influence on evolutionary thought. We must pass at once to the great figure of Lamarck (1744–1829). We have already mentioned (Chapter X, p. 108) the two factors of evolution with which the name of Lamarck is associated, and have noted the fact that Erasmus Darwin (1737–1802), grandfather of Charles Darwin, seems to have anticipated Lamarck's views in part.

Lamarck's four propositions are as follows :

First Law. Life by its own activities tends continually to increase the volume of every body that possesses it, and to increase the size of all the parts up to a limit which it itself imposes.

Second Law. The production of a new organ or part results from a new need, which continues to be felt, and from the new movement which this need originates and sustains.

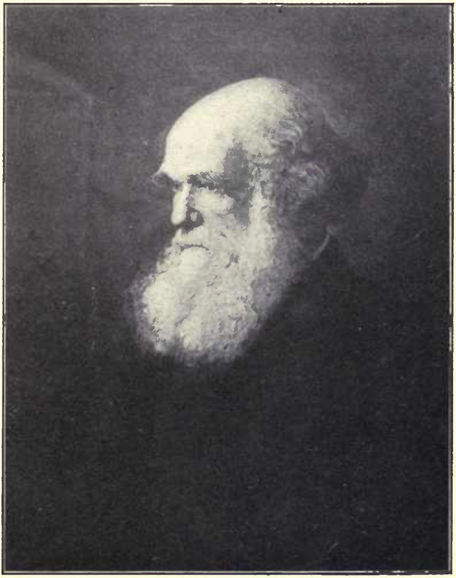


Fig. 233. Charles Darwin

Third Law. The development of organs and their power of action are always in direct relation to the employment of these organs.

Fourth Law. All that has been acquired or changed in the structure of individuals during their life is preserved by generation and transmitted to new individuals which have undergone these changes.

Discussion of the validity of these principles still continues. Though Lamarck's influence can be traced in his contemporaries and those who followed him, it does not seem that he directly affected the far more important work of Darwin.

Without doubt biology owes a greater debt to Charles Darwin (1809–1882, Fig. 233) than to any other man. He compelled the attention of men in a way and to an extent unsurpassed by any other writer. His labors were directed not alone towards stating the doctrine of descent with modification and marshaling evidence to its support, but he promulgated the theory of natural selection as the main though not the chief factor in evolution. His work was a triumph for the inductive method, for never before had such an array of facts been collected and presented. The battle was first fought over the fixity of species, till belief in that theory no longer became possible. Then investigators sprung up on every side, stimulated by the brilliancy and simplicity of natural selection (to which Darwin afterwards added sexual selection), or anxious to disprove its validity as a factor in evolution.

When twenty-two years of age Darwin sailed on H.M.S. *Beagle* on a voyage to South America and around the world. He returned to England, his interest in natural history strengthened and the problems of life outlining themselves to him. This voyage was the beginning of the collection of that vast store of facts which were afterward organized and used with such effect. For over twenty years he worked getting together facts which had to do with the variation of animals and plants, and thinking on the general problem. And now occurred one of the most remarkable coincidences in the whole history of science. While Darwin was elaborating his views on the mutability of species Alfred Russel Wallace (born 1822), an English naturalist then in the Malay Archipelago, arrived at practically the same conclusion that Darwin had reached. By the aid of friends it was arranged that publication should be simultaneously made, and therefore in the *Journal of the Linnæan Society* of London of June 30, 1858, we find two papers of transcendent interest. The one by Darwin consists of portions of manuscript written in 1839 and 1844, entitled *On the Variation of Organic Beings in a State of Nature; on the Natural Means of Selection; on the Comparison of Domestic Races and True Species.* Wallace's paper is *On the Tendency of Varieties to depart indefinitely from the Original Type.* A year afterward appeared Darwin's

Origin of Species, in which the theory of natural selection was elaborated. The main features of the theory have already been outlined in Chapter X. Darwin was a prolific writer; some of his books are *On the Variations of Animals and Plants under Domestication*, *The Descent of Man*, and *The Expressions of the Emotions in Man and the Lower Animals.* In all of these natural selection is applied.

Among the contemporaries who aided Darwin in his work, and who were in turn influenced by him, may be mentioned the names of Herbert Spencer (1820–1903), the philosopher and author of the *Principles of Biology;* Ernst Haeckel (born 1834), the brilliant author of *General Morphology ;* Thomas H. Huxley (1825–1895), a great teacher and popularizer of zoölogy, and author of important works; and, finally, August Weismann (born 1834), who aroused skepticism as to the hereditary transmission of acquired characters, and who has made important supplementary contributions to the theory of natural selection.

It is impossible to overestimate the influence of the selection theory in the progress of modern zoölogy. It has thrown new light on all fields of activity, so that it may be said that a new science of zoölogy has arisen. The importance of careful experiment has been appreciated as never before. A host of investigators have sprung up, whom to merely mention would transcend the limits of this work. The work of a very few men has been referred to in the preceding chapters, in the effort to give some picture of the state of the science of zoölogy to-day. Everywhere zoölogists are endeavoring to learn the truth about animals, trying to understand better the problem of animal life, and the greatest problem of all, towards which the solution of all others is directed, —the problem of man and his relation to the universe.

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